SEPTEMBER 2015

GLASTIR MONITORING & EVALUATION PROGRAMME

SECOND YEAR ANNUAL REPORT

APPENDICES

Prepared by CEH on behalf of the Glastir Monitoring & Evaluation Programme Team

Canolfan Ecoleg a Hydroleg
CYNGOR YMCHWIL YR AMGYLCHEDD NATURIOL

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

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Answers to some questions you might have

What is Glastir?
Glastir is a land management scheme aimed at improving water and soil management, maintaining and enhancing biodiversity, improving our climate, managing and protecting the historic Welsh landscape, creating new opportunities to improve access and increasing the area and management of woodlands.

What's the survey all about?
The Glastir Monitoring and Evaluation Programme (GMEP) uses a scientifically-rigorous approach to monitor and evaluate the impacts of Glastir. The evidence-gathering components of GMEP are split into two elements;

i) A targeted survey to identify impacts of specific Glastir measures within the advanced element of the scheme.
ii) A wider survey to identify ongoing changes to the countryside in Wales against which changes to land within the Glastir advanced element can be compared.

The information gathered during the survey will be used to assess the likely success of Glastir and inform the Welsh Government and public.

What will the survey teams be doing?
Specialist field teams will visit your landholding to collect data on i) freshwater quality and biodiversity; ii) pollinating invertebrates; iii) birds; and iv) habitats, landscapes and historic features and soils.

When will the survey teams arrive on my land?
The surveys are carried out between April and September 2014. We will contact you two weeks prior to the survey teams arriving to make final arrangements and discuss any other issues you might want the surveyors to know about. Your valuable contribution helps strengthen the survey and contributes to Wales providing global leadership in agricultural and environmental stewardship.

How was I selected?
No individual person was selected. Land eligible for Glastir advanced payments and land outside the advanced scheme were chosen at random and landowners contact details provided by Welsh Government. So you personally weren't selected, your land was.

What about privacy?
The Centre for Ecology & Hydrology is committed to the highest levels of data security and maintaining individual privacy. All information collected through the survey will be treated in the strictest confidence and will be used for statistical purposes only. Individuals or their landholdings are never identified when reporting the results of the survey.

Who can I contact about the survey?
If you have any questions or thoughts regarding the survey, please don't hesitate to contact the GMEP Survey Office on: **01248 374500** or email gmep@ceh.ac.uk

Atebion i rai cwestiynau yr hoffech efallai eu gofyn

Beth yw Glastir?
Cynllun rheoli tir yw Glastir a'r nod yw gwella rheolaeth dŵr a phridd, , cynnal a gwella bioamrywiaeth, gwella ein hinsawdd, rheoli a diogelu tirwedd hanesyddol Cymru, creu cyfleoedd newydd i wella mynediad a chynyddu ardal a rheolaeth coetiroedd.

Beth mae'r arolwg yn ei olgyu?
Mae Rhaglen Fonitro a Gwerthuso Glastir (RhFGG) yn defnyddio dull manwl wyddonol o fonitro a gwerthuso effeithiau Glastir. Mae cydrannau casglu tystiolaeth RhFGG wedi'u rhannu'n ddwy elfen;

i) Arolwg wedi'i dargedu er mwyn nodi effeithiau mesurau penodol Glastir o fewn elfen ddatblygedig y cynllun.
ii) Arolwg ehangach i nodi newidiadau parhaus i gefn gwlad yng Nghymru, yn erbyn yr hwn y gellir cymharu newidiadau i dir o fewn elfen ddatblygedig Glastir..

Bydd y wybodaeth a gesglir yn ystod yr arolwg yn cael ei ddefnyddio i asesu llwyddiant tebygol Glastir ac i ddarparu gwybodaeth i Lywodraeth Cymru ac i'r cyhoedd.

Beth fydd timau'r arolwg yn ei wneud?
Bydd timau maes arbenigol yn ymweld â'ch daliad tir i gasglu data ar i) ansawdd dŵr croyw a bioamrywiaeth; ii) infertebratau sy'n peillio; iii) adar; a iv) cynefinoedd, tirweddau a nodweddion hanesyddol a phriddoedd.

Pryd fydd y timau arolygu yn cyrraedd fy nhir?
Mae'r arolygon yn cael eu gwneud rhwng mis Ebrill a mis Medi 2014. Byddwn yn cysylltu â chi bythefnos cyn i'r timau arolwg gyrraedd i wneud trefniadau terfynol ac i drafod unrhyw faterion eraill yr hoffech chi efallai i'r syrfewyr gael gwybod amdanynt. Mae eich cyfraniad gwerthfawr yn help i gryfhau'r arolwg ac mae'n gymorth i Gymru ddarparu arweinyddiaeth fyd-eang mewn stiwardiaeth amaethyddol ac amgylcheddol.

Sut cefais i fy newis?
Ni chafodd unrhyw berson unigol ei ddewis. Cafodd tir sy'n gymwys am daliadau uwch Glastir a thir y tu allan i'r cynllun uwch eu dewis ar hap a Llywodraeth Cymru wnaeth ddarparu manylion cyswllt tirfeddianwyr . Felly, nid chi yn bersonol gafodd eich dewis , ond eich tir.

Beth am breifatrwydd?
Mae'r Ganolfan Ecoleg a Hydroleg wedi ymrwymo i'r lefelau uchaf o ddiogelwch data ac i sicrhau preifatrwydd unigol. Bydd yr holl wybodaeth a gesglir drwy'r arolwg yn cael ei drin yn gwbl gyfrinachol a chaiff ei defnyddio at ddibenion ystadegol yn unig. Ni fydd unigolion, na'u tirddaliadau yn cael eu nodi wrth adrodd canlyniadau'r arolwg.

Gyda phwy allaf i gysylltu ynglŷn â'r arolwg?
Os oes gennych unrhyw gwestiynau neu sylwadau ynglŷn â'r arolwg, mae croeso i chi gysylltu â Swyddfa Arolwg RhFG Glastir ar : 01248 374 500 neu e-bostiwc bpgmep@ceh.ac.uk

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

Canolfan Ecoleg a Hydroleg/
Centre for Ecology & Hydrology
Canolfan yr Amgylchedd Cymru/
Environment Centre Wales
Ffordd Deiniol/Deiniol Road, Bangor
Gwynedd, LL57 2UW, United Kingdom

Ffôn/Tel: +44 (0) 1248 374500
Ffacs/Fax: +44 (0) 1248 362133
www.ceh.ac.uk

Ref no.

15th November 2013

Dear ,

Re : Glastir Monitoring and Evaluation Programme – Summer 2014

I am writing to let you know that the Centre for Ecology & Hydrology (CEH), on behalf of the Welsh Government, will be undertaking field surveys next summer as part of the Glastir Monitoring and Evaluation Programme (Glastir MEP).

The Glastir MEP will monitor and evaluate Glastir against broader baseline environmental information from across Wales, including those farms NOT participating in Glastir. The Glastir MEP is a partnership of 17 institutions who will evaluate the impact of the scheme and the wider Wales countryside on habitats, species, water, soils, climate, landscape, wider social benefits and economics.

Your land has been randomly identified for survey

We have randomly selected areas of land across Wales to assess the Welsh countryside and impacts of Glastir. This letter is to let you know that your land has been randomly identified for survey and we would like to visit your farm to carry out this work. If you are not a Glastir contract holder and have any reservations can you please contact me to discuss.

The survey we are conducting is not related in any way to compliance or the inspection process for Glastir, Single Payment Scheme, or any other scheme, and will not affect your payments.

The surveyors will be visiting your area during summer 2014. You are not required to accompany the surveyors. I or the survey team leader will contact you nearer the time to let you know details of our movements on the day, and registration of the vehicle. If you wish, the surveyors can meet you during the visit and explain what the survey involves. An overview of the survey is included with this letter.

Your personal data is protected by the Data Protection Act 1998. The information we gather through the survey will be the property of the Welsh Government and will be subject to the appropriate data security restrictions. Individual land owner's names and land holdings will not be identified in reporting. Data collected from the survey will be presented in summary form only (e.g. by region or habitat type).

We assure you that we will take great care of your land and property and follow strict bio-security measures required by Welsh Government when undertaking the survey. If there are other people who will need to know of our presence e.g. tenant farmers, gamekeepers, please could you let the surveyors know who to contact.

In any future correspondence I will use the password "*Jackdaw*" to confirm my identity.

Yours Sincerely,

A Owen

Anthea Owen,
Glastir MEP Farmer Liaison Officer

Canolfan
Ecoleg a Hydroleg
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Canolfan Ecoleg a Hydroleg/
Centre for Ecology & Hydrology
Canolfan yr Amgylchedd Cymru/
Environment Centre Wales
Ffordd Deiniol/Deiniol Road, Bangor
Gwynedd, LL57 2UW, United Kingdom

Ffôn/Tel: +44 (0) 1248 374500
Ffacs/Fax: +44 (0) 1248 362133

www.ceh.ac.uk

Rhif cyf.

15ed Tachwedd 2013

Annwyl

Par : Rhaglen Fonitro a Gwerthuso Glastir – Haf 2014

Rwy'n ysgrifennu atoch i roi gwybod i chi fod y Ganolfan Ecoleg a Hydroleg (CEH), ar ran Llywodraeth Cymru, yn cynnal arolygon maes yn ystod yr haf nesaf fel rhan o 'Raglen Fonitro a Gwerthuso Glastir (RhFG Glastir).

Bydd RhFG Glastir yn monitro a gwerthuso Glastir yn erbyn gwybodaeth waelodlin amgylcheddol ehangach a gasglwyd ledled Cymru, gan gynnwys y ffermydd hynny sydd DDIM yn rhan o Glastir. Partneriaeth o 17 o sefydliadau yw RhFG Glastir a bydd yn gwerthuso effaith y cynllun a chefn gwlad ehangach Cymru ar gynefinoedd, rhywogaethau, dŵr, priddoedd, hinsawdd, tirwedd, buddiannau cymdeithasol ehangach ac economeg.

Mae eich tir wedi cael ei nodi ar hap ar gyfer cynnal arolwg

Rydym wedi dewis ar hap ardaloedd o dir ledled Cymru i asesu cefn gwlad Cymru ac effeithiau Glastir. Diben y llythyr hwn yw rhoi gwybod i chi bod eich tir wedi cael ei nodi ar hap i fod yn rhan o'r arolwg a byddem yn hoffi ymweld â'ch fferm i wneud y gwaith yma. Os nad oes gennych gontract Glastir a'ch bod yn bryderus ynglŷn â hyn a wnewch chi os gwelwch yn dda gysylltu â mi i drafod.

Nid oes cysylltiad o gwbl rhwng yr arolwg rydym ni yn ei wneud â chydymffurfio nac â phroses arolygu Glastir, y Cynllun Taliad Unigol nac unrhyw gynllun arall ac ni fydd yn effeithio ar eich taliadau.

Bydd y syrfewyr yn ymweld â'ch ardal yn ystod haf 2014. Nid oes angen i chi hebrwng y syrfewyr o gwmpas y tir. Byddaf i neu arweinydd tîm yr arolwg yn cysylltu â chi yn nes at yr amser i roi gwybod i chi beth fydd ein cynlluniau ar y diwrnod a rhif chofrestru ein cerbyd. Pe baech yn dymuno hynny, gall y syrfewyr gwrdd â chi yn ystod yr ymweliad i egluro beth fydd yn digwydd yn ystod yr arolwg. Mae trosolwg o'r arolwg wedi'i atodi gyda'r llythyr hwn.

Mae eich data personol yn cael ei ddiogelu gan Ddeddf Diogelu Data 1998. Eiddo Llywodraeth Cymru fydd y wybodaeth y byddwn yn ei gasglu yn ystod yr arolwg a bydd yn atebol i'r cyfyngiadau diogelwch data perthnasol. Ni fydd perchenogion tir unigol yn cael eu henwi na manylion daliadau tir yn cael eu datgelu yn yr adroddiad. Bydd data a gasglwyd yn ystod yr arolwg yn cael ei gyflwyno ar ffurf crynodeb yn unig (e.e. yn ôl rhanbarth neu'r math o gynefin).

Rydym yn eich sicrhau y byddwn yn cymryd pob gofal o'ch tir a'ch eiddo a byddwn yn dilyn y mesurau bio-ddiogelwch llym sy'n ofynnol gan Lywodraeth Cymru wrth gynnal yr arolwg. Os oes yna bobl eraill sydd angen gwybod am ein presenoldeb e.e. tenantiaid fferm neu giperiaid, buasem yn ddiolchgar petaech yn gadael i'r syrfewyr wybod â phwy y dylent gysylltu.

Er mwyn i chi wybod mai fi sy'n cysylltu â chi, byddaf yn defnyddio'r cyfrinair 'Jac Do' mewn unrhyw ohebiaeth yn y dyfodol.

Yr eiddoch yn gywir,

AOwen

Anthea Owen
Swyddog Cyswllt Ffermwyr RhFG Glastir

GLASTIR
QUALITY ASSURANCE EXERCISE

FIRST DRAFT (2/12/2104)

Hilary Wallace and Mike Prosser
Ecological Surveys (Bangor)

The School House, Canon Pyon, Herefordshire, HR4 8PF.
MikeHilary@ecosurvey.demon.co.uk

Report to Centre of Ecology and Hydrology, Lancaster.

GLASTIR: QUALITY ASSURANCE EXERCISE

SUMMARY

Introduction

It is recognised that all field investigation involving a large number of surveyors must produce an inherent degree of variation despite the provision of a training course, a field handbook and on-site visits by supervisors (Quality Control). It is therefore important to attempt a measure of the consistency and reliability of the work done within the major components of the field programme (Quality Assurance). This report addresses the quality of the botanical recording across the various plots types surveyed during the 2014 Glastir field season.

A sample comprising 6 squares surveyed in 2014 was selected and in each of these one quarter was selected for re-surveyed. Within each quarter 2 examples of each plot type were selected; where 2 plots were not available the survey extended to the next quarter of the square. The re-survey involved the recording of 67 plots.

Species-richness

A basic measure of the standard of botanical recording is given by comparing the mean number of species per plot recorded by the surveyors compared with that found by the assessors. The values across all plots for Glastir 2014 are Surveyors 20.0 species/plot, QA assessors 22.0 species/plot. This is an improvement from CS 20007 when the equivalent values were surveyors 17.5 species/plot and assessors 21.7 species/plot.

Mis-matches in the species record.

Mis-matches have been apportioned into a series of categories which reflect the nature of individual non-concordances.

Variation at time of survey (T1 variations)

- Mis-identification
- Species present but overlooked
- Over-zealous recording
- Mysteries including tablet errors
- Location/orientation errors.

Variations at time of QA (T2 variations)

- Management changes
- Seasonal changes
- Orientation errors
- Species present but overlooked

Of these, by far the greatest source of error was the over looking of species by the surveyors (53.0% of all mis-matches). Management changes, seasonal changes and over-zealous recording make only very modest contributions to the total non-concordance. The mis-identification of species (at 7.1% of errors) is very similar to that found in previous CS surveys.

Recording of plot types.

The different plot types have been recorded more consistently than in previous surveys, falling within a range of 87.3% of species recorded in the QA appearing in the surveyors record for Hedge plots to 95.5% for the U plots. The value for the U plots is misleading since there were only six plots compared to the 19 of CS 2007 when the corresponding

value was only 74.1%; for Glastir 2014 three of the U plots were in a square that was exceptionally well surveyed.

Percentage accuracy of survey.

Percentage accuracy (common species/cumulative species list from T1 plus T2 species - T2 errors) shows an improvement on CS2007 of 66.8% compared to 62.2% though the range across the six squares is considerable, ranging from 75.2% for square 12334 to only 58.6% for square 41349.

Recommendations.

- Introduce sighting compasses.
- Always make clear whether a tape or range finder has been used
- Keep sketches simple
- Carry out a pre-survey trial to test the efficiency of the Trimble for plot relocation
- More practice is grass ID during training courses
- Emphasise the importance of photograph and necessity of indicating position of photograph on sketch
- Better instruction in individual plot location protocols - return to CS survey where much emphasis was placed on the positioning of individual plots relative to the X plot. In particular relative position of Hedge to Boundary and Diversity to Hedge.
- Cover a wider range of landscape types in future QA exercises

INTRODUCTION

1 It was recognised during the Countryside surveys of 1990, 1998 and 2007 that field investigations involving large numbers of recorders and surveyors must produce an inherent degree of variation despite the provision of a training course, a field handbook and on-site visits by supervisors (Quality Control). It is therefore important to attempt a measure of the consistency and reliability of the work done within the major components of the field programme (Quality Assurance).

2 The current exercise is confined to an examination of the botanical recording of vegetation plots during the 2014 Glastir survey and follows the same methodology as that developed for the quality assurance (QA) exercises conducted during the 1990, 1998 and 2007 Countryside Surveys. The efficiency of the mapping component of Glastir was tested in a separate exercise.

3 Six of the 90 squares surveyed during the 2014 field season was selected for QA, comprising two from each of the three regions. In each of these one quarter of the 1km square was targeted. As far as possible two examples of each plot type were included in the QA programme for each square though the scarcity of U plots and A (arable) plots resulted in these being under-represented in the total.

4 In addition to the need for a measure of the dependability of the botanical recording during the current Glastir survey it was felt desirable to make some comparison between the Glastir QA exercise and those of the CS exercises.

5 In total 67 plots were recorded across the eight plot types. Seven of these plot types were also recorded during the CS surveys; however road verges were not recorded during Glastir but P-plots were introduced; a 10m linear plot running perpendicular from the stream (S or W) into the adjacent land parcel.

6 During the 2007 Countryside Survey a number of parameters were considered in order to assess the efficiency of botanical recording and most of these have been measured during the Glastir exercise, albeit with a much smaller sample size. The principal factors include the efficiency of plot location (relocation errors on the part of the surveyors are not covered in the current exercise since all squares were surveyed for the first time in 2014), measures of species-richness and reasons for discrepancies in the total species record. Measures of species' frequency and cover are not addressed here due to the small sample size. Finally, an assessment is made of the likely consequences of these variations on assessments of vegetation change.

METHODS.

Plot selection

7 The protocol for the selection of the quarter of the square to be used in the QA exercise was as follows:

The quarter should ideally include examples of all the different plot types
It should be relatively easily accessible
It should have few land owners.

The map of plots recorded was initially studied for the SE quarter of the square: if this area met the criteria it was selected for QA, if not, attention shifted to the SW quarter, then NW and finally NE until the most appropriate quarter had been established.

8 The full list of squares monitored, with times of original survey and assessment resurvey, is given as Annex A.

9 The eight plot types used in the survey and re-examined as part of the QA exercise may be sub-divided into quadrats and linear plots:

Quadrats:

$200m^2$	X plots	Random points
$4m^2$	Y plots	Targeted habitats
$4m^2$	U plots	unenclosed (BAP) broad habitats.

Linear plots, all 10m x 1m, which comprise:

H: Hedges, running parallel with the hedge line and commencing at the mid-point of the hedge. Simple 50m hedgerow diversity plots, introduced in 1998, were also included in the QA exercise but data are not presented here.

S: Streamsides, from normal water level or at the lower limit of vegetation cover in the case of water courses with extensive gravel or pebble beds etc. Additional plots on larger water ways are designated W and are amalgamated with the S plots in the analyses.

P: Perpendicular streamside plots, upslope habitats adjacent to and centred on the S/W plots. A new plot type introduced as part of the Glastir monitoring program.

B: Boundaries, in enclosed land only; recorded at the boundary marker (GPS) point associated with the $200m^2$ X plot.

A: Arable. 100m x 1m arable field margin plots. Recently introduced to CS, only a single sample was recorded during the Glastir QA exercise.

Field survey

Plate and plot relocation

10 No metal plates were used during the Glastir botanical survey, instead an accurate dGPS was used to fixed the corner/end of plot previously marked with a metal plate. Since the dGPS was not available during the QA exercise the accuracy of relocation using this device has not been tested. The Glastir QA exercise therefore relied entirely on the sketch maps and photographs for plot relocation. In unenclosed areas the internal GPS of the Getac was often used to get within 2-3m of the plot with final positioning relying on sketches and photos.

The species record

11 The same basic methodology for recording the species complement of the plots was adopted as that used for the CS QA exercises. Plots were recorded using a standardised data sheet, all species of vascular plant and allowed cryptogams were listed and then assigned cover values using 5% cover bands. The plots were first recorded 'blind' (without reference to the surveyors data) and then compared with the surveyors record. Discrepancies between the two species lists were initially identified in the field and reasons sought for the non-concordant records.

DATA PRESENTATION

12 *Plot location.* A summary of the plot relocation rates for all QA exercises is presented (Annex B).

13 *Species richness*. The simplest comparison between the Surveyors and QA species records involves assessment of species number/plot. ANOVA and Tukey Pairwise comparisons are used to test for significant differences between Surveyors and QA assessors. Results are also compared against those of the CS surveys (1990, 1998 and 2007).

14 *Mis-matches in the species record*. Although a basic comparison for each plot can be made between the results of the initial survey and the subsequent QA record, it is more instructive to compare the species lists critically and to apportion the mis-matches into a series of categories which reflect the nature of individual non-concordances. Ten such categories were established during the CS exercise and these have been adopted for Glastir with a few minor modifications. These data are used to arrive at values for the actual efficiency of the surveyors recording both by plot and by square.

15 **T1 variations.** Species recorded by Glastir Surveyors but not confirmed for the plot by the Assessors (QA) or species present in the QA assessors plot but omitted from the Surveyors plots. Some categories recognised in the CS1990 QA assessment were amalgamated for the 1998 and 2007 assessments and this protocol has been adopted for the Glastir exercise.

A:** mis-identifications.** Three forms of non-concordance are amalgamated under this heading.

i. Species incorrectly identified and forming a couplet with the, hopefully, correctly identified species recorded at QA; *Rumex crispus (*Surveyor) *versus Rumex sanguineus* (QA) being a common example.

ii. Species not apparently forming a couplet with any species recorded during the QA exercise e.g. where both *Ranunculus repens* and *R.bulbosus* appear in the T1 record but only one of these species was found at T2.

iii. Apparent inputting errors: in previous surveys it was not unusual for a surveyor to tick the wrong box on the data sheet thus allocating a record to an adjacent species. *Primula vulgaris-Prunella vulgaris* and *Ranunculus flammula-Ranunculus ficaria* were the most frequently encountered examples. An analogous error seems to occur with the use of the Tablet.

***B:** Species considered to have been overlooked during the initial recording*

In contrast to CS all the plots recorded in Glastir 2014 were 'new' plots and thus no errors can be associated with incorrect relocation of plots by the surveyors.

In some instances it was clear that a plot was not placed in accordance to the guidelines, but was none the less relocatable during the QA exercise. In these cases the plot was recorded and its incorrect positioning just noted for guidance to future surveyors. Where QA relocation/orientation was uncertain and it was apparent that the original and QA plots only partially overlapped, a search was made of the extended area missed by the QA assessor for species recorded at T1 and these are assigned to J rather than B errors.

C:** Over-zealous recording.** During the QA exercise particular care was taken to restrict recording to the exact plot size stipulated. The surveyors had, in some instances, not adequately measured the plot or had included species adjacent to but not strictly within the defined area. Such errors were most prevalent with stream plots where an inflated distance from water level was sometimes used and hedge plots where the recording area extended too far into the adjacent sward.

***D:** Mysteries*. Species records, apparently incorrect, for which no reasonable explanation could be advanced. Some of these are likely to be ‘tablet’ errors where a ghost record of a most improbable record may occur. A possible source of this error is where a common species is selected to get into the drop down list and then the wrong species is selected; e.g. *Trifolium repens* registered rather than *Triglochin palustre*. These errors are not always easy to spot and quantify.

J:** Location / orientation errors.** In previous QA exercises distinctions were made between non-concordances due to the incorrect orientation of a plot which was otherwise adequately located and mis-matches in the records due to the surveyors either being in the wrong place e.g. a B plot starting from the wrong whitebeam, or recording in the wrong direction e.g. going the wrong way from a plate. A further distinction was made between species recorded that should not have been and species missed as a result of incorrect position. These causes of mis-matches with the QA have been amalgamated into a single T1 location error.

16 **T2 Variations.** Species not recorded by the QA assessors but recorded by the Glastir surveyors or, *vice versa*, where the species concerned was most probably part of the T1 ‘real’ plot record.

***E:** Species mis-matches due to management changes in plots between Glastir survey and QA assessment.* These involve changes in crop type, changes in species recorded due to crop management, hay cutting etc. They represent species which were very probably present when the Surveyors recorded the plot but which were no longer evident at the time of the QA. Conversely, regrowth of species by the time of the QA assessment in plots which had been recently mown at time of the original survey.

***F:** Species mis-matches due to seasonal changes between Survey and QA assessment.*

These non-concordances often represent vernal species which were not identifiable late in the season when the QA was undertaken. For the Glastir QA most plots were re-visited within 3 weeks of initial survey and hence 'F' errors should be low.

***G/H mis-matches:** Orientation errors.* In early QA work a distinction was made between non-concordances due to misalignment of the position of the plot by the assessors and misorientation of a plot. These have been amalgamated. For CS surveys recourse to previous plot records was often helpful in recognising these errors of positioning on the part of the assessors; no such historic records exist in Glastir and so these errors may be greater.

***I:** Species missed by the QA assessors*. Species which were in the plot but only recorded when the plot was searched a second time during the comparison of the initial QA record with the Surveyors record.

17 **Other variations.**

***K:** Species mis-match due to location problems.*

Mismatches due to uncertainty of whether the Surveyor or QA assessor is in the wrong place. This was used in assessing change over time in CS; since all the Glastir plots are first time records this error has not been used in 2014.

18 **Summary of recorder errors.**

19 *Percentage Agreement*. A crude but objective means of comparing two species lists. Percentage Agreement = Species common to both samples/Aggregated species list from both samples expressed as a percentage. % Agreement is presented for each plot in each square (Annex B, see excel file Glastir_QA14.xls).

20 *Percentage Efficiency*. This is a measure of the surveyors' accuracy and is calculated having removed discrepancies which can be attributed to the QA assessor, usually relating to changes in species present due to seasonal effects, management or location errors.

RESULTS

21 Annex A presents a summary of the squares surveyed during the QA exercise with dates of initial survey and QA assessment. Annex B provides a summary of the allocation of species mis-matches.

Plot relocation.

22 One of the specific objectives of the QA exercise was to assess the efficiency of plot location prior to recording. Using a combination of the sketch maps and, crucially, the original photographs, the assessors failed adequately to locate (within 2m) 11 of the 68 plots: a percentage recovery of 83.8%. This recovery rate is remarkably similar to previous QA exercises CS1990 (87.1%), CS1998 QA (86.7%) and CS2007 QA (86.5%). This is a clear demonstration of the effectiveness of the sketches and photos approach to the re-finding of plots.

The species record

Species richness.

23 Across the 67 plots assessed the Surveyors recorded, on average, fewer species per plot than the QA assessors. The sample size for each individual plot type was small, and significant differences were only noted for the B, S and Y plots.

24 The expression of the Glastir surveyor's species richness value as a percentage of the QA assessor's value provides a simple means of comparing the efficiency of recording of the different plot types. The overall value of 90.9% compares favourably with the previous CS QA exercises of CS1998 (87.7%) and CS2007 (80.71%). The Glastir range is small (between 87.3 for the H plots and 95.5% for the P plot), and thus shows a similar level of consistency across the plot types to the 1998 survey (82.4-90.2). In CS2007 variation was greater, most plot types fell below 80% with a range of 74.1% to 95.8%.

25

Table 1a.Comparison of species number per plot recorded by the Glastir 2014 Surveyors (Glastir) and the 2014 Quality Assurance assessment (QA). Values are mean species/plot; *p* values are for paired t-test. The final column expresses the Surveyor surveyors' records as a percentage of the QA assessors.

Plot type	Number of samples	Surveyors	QA	Paired t-test	Surveyor % of QA
All plots	67	20.00	22.00	<0.001	90.9
X	12	22.08	23.75	0.222	93.0
Y	9	13.88	15.33	0.044	90.5
H	9	18.33	21.00	0.057	87.3
P	10	21.5	22.5	0.148	95.5
B	10	19.30	21.90	0.040	88.1
U	6	21.5	22.5	0.148	95.5
S	10	27.6	31.0	0.027	89.0

Table 1b.Comparison of species number per plot recorded by the CS 2007 surveyors (CS2007) and the 2007 Quality Assurance assessment (QA 2007). Values are mean species/plot; *p* values are for paired t-test. The final column expresses the CS 2007 surveyors' records as a percentage of the QA assessors.

Plot type	Number of samples	CS 2007	QA 2007	Paired t-test	CS 2007 % of QA
All plots	266	17.49	21.67	<0.001	80.71
X	51	19.82	24.57	<0.001	80.67
Y	44	12.23	15.82	<0.001	77.31
H	26	18.04	19.19	0.257	94.01
R	39	20.59	25.90	<0.001	79.50
B	43	16.86	21.37	<0.001	78.90
U	19	12.84	17.32	<0.001	74.13
A	7	19.71	20.57	0.861	95.82
S	37	19.60	24.73	<0.001	79.26

26 In common with the results from the Countryside Surveys and their QA programmes, the mean species per plot recorded by the assessors was greater than that for the same plots at the time of the initial survey. The impression gained in the field in the Glastir QA was that grasses had been more poorly recorded than in previous surveys but that recording of allowable bryophytes and lichens present was possibly better than in CS 2007. Table 2 presents values for the under-recording of species (as a percentage of the QA record) when partitioned into species groups. Data presented are the total records for each taxanomic group. Overall, the percentage recorded by Surveyors has dropped compared to the CS2007 (80.7%) suggesting a generally poor search image. Grasses were better recorded in CS2007 (85.3%) but the Glastir recording of cryptograms (67.5%) has improved considerably in comparison to the CS2007 value of only 40.2%.

Table 2. Effectiveness of recording by species group.

Species group	Glastir Records	QA Record	Percentage recorded by surveyors
All species	1339	1747	76.7
Cryptograms	156	231	67.5
Grasses	370	470	78.7
Others	813	1046	77.7

Allocation of sources of error in the species record

27 Table 3 presents a summary of the allocation of the mis-matched species records as a proportion of the total mis-matches. For example, there were 1353 records of species

having been over-looked by the CS surveyors, this equates to 48.9% of the total errors. Annex B presents the attribution of mis-matches to each of the 10 categories used for each plot recorded together with the values for % accuracy by plot.

28 Table 4 presents a summary of the equivalent values for the CS QA exercises.

Table 3. Allocation of sources of error in the species record for the Glastir Survey. Total errors = 613 mis-matched species records. These can be apportioned between errors arising from the 2014 surveyors (T1 errors) and those occurring during the QA exercise (T2 errors).

T1 MIS-MATCHES

Category	Description	Number of records	% of total
A	Species mis-identified	43	7.1
B	Species overlooked	325	53.0
C	Over-zealous recording	17	2.8
D	Mysteries	66	10.8
J	Plot mis-alignment/orientation	12	1.9

T2 MIS-MATCHES

E	Species change due to management	4	0.6
F	Seasonal changes	17	2.8
G/H	T2 Location/orientation uncertain	62	10.1
I	Overlooked by the assessor	67	10.9

UNCERTAIN LOCATION ERRORS

K	Location problems: unclear if Surveyor or QA in wrong place	0	0

Table 4. Allocation of mis-matched records: Summary comparison CS 1990, 1998 and 2007 CS surveys.

Type	% total error 1990	% total error 1998	% total error 2007	% total error Glastir 2014
Surveyor mis-matches				
A	6.3	8.5	7.8	7.1
B	34.5	39.8	48.9	53.0
C	5.8	1.9	1.9	2.8
D	2.8	4.6	5.2	10.8
J	3.7	19.9	14.5	1.9
QA mis-matches				
E	3.4	2.0	1.6	0.6
F	20.8	3.7	5.0	2.8
G/H	17.7	9.2	5.2	10.1
I	5.0	10.4	4.2	10.9
Uncertain location errors			5.6	0.0

29 The percentage of mis-identified, overlooked or over zealous records are very similar to the CS 2007 results. However, the percentage of mysteries has more than doubled, many of these are likely to be tablet errors; a good example being the lack of *Hypnum jutlandicum* whilst random records for species that were not apparently present were also common. The lack of metal plates for confirmation of accurate plot relocation has resulted in a rise in T2 errors due to uncertain relocation of plots. The lack of sighting compasses for the Surveyors often resulted in impossible triangulation for the QA assessor resulting in both location and orientation errors between the Surveyor and Assessor. The rise in species overlooked by the assessor can, in part, be attributed to the QA exercise being carried out by a single assessor. Also, the proportion of lowland relative to upland squares in which species turnover tends to be higher.

30 An alternative approach is to express the mis-matches as a proportion of the total species record: in this case the combined Surveyor and QA species record is 1747. This is the crudest form of comparison, and gives an overall % agreement based on the total species record. The cumulative T1 error of 26.4% equates to a % agreement of 73.6%. The comparable CS figures were 79.3% (CS1990), 73.1% (CS1998) and 65.6% (CS 2007).

Tablet errors.

31 An attempt had been made in 2007 to assess the likely increase in recorder error introduced through the use of the computer tablet. During that QA exercise a number of plots were recorded simultaneously on the tablet and as paper copy by the pair of QA assessors. Since the Glastir QA was conducted by a single assessor this was not possible; however plots were entered onto the tablet either during field survey or subsequently in the office. Comparisons of the species record, and cover values, could be used to give some insight into the likely errors arising from tablet use.

32 Surveyor tablet errors are harder to assess as there is no paper trail to follow. A few plots appeared to have a large number of ghost records (assigned D errors), these may counter balance 'B' errors where a wrong species has been ticked. If a species present at T1 has been mis-recorded due to the tablet picking the wrong species e.g. *Molinia caerulea* recorded when the original species was *Montia fontana*, then *Montia* will be classed as overlooked whilst *Molinia* becomes a 'Mystery' when the QA assessor visits the plot. Similar errors were noted for *Ranunculus ficaria* versus *Ranunculus flammula*, *Trifolium repens* versus *Tripleurospermum*, *Trifolium repens* versus *Triglochin palustre*. At least 7 instances of this type were noted. The omission of *Hypnum jutlandicum* from the tablet records has hopefully been resolved.

33 The use of the computer tablet has introduced an additional dimension to the recording which is akin to the ‘wrong’ box ‘mis-identification’ error of the 1990 QA exercise. Wrong entries on the tablet may also account for some of the unknowns where the wrong species is selected from the drop-down extended species list. Whether the increases in overlooked species can in any way be attributed to the use of the tablet is less clear; it is possible that in trying to add extra species from the drop down menu a previously recorded species has been over-written, also the time taken to find species might have resulted in the next called species being missed; however, on balance it would seem that the greater reason for an increase in overlooked species is the failure of the recorder to recognise species that are present.

Percentage Agreement

34 This is the crudest, and simplest, measure of the level of agreement between two independently collected species lists. The number of species common to both lists is divided by the aggregate of all species recorded at time one (T1) and at time two (T2) and then expressed as a percentage (Annex B).

35 Percentage agreement = Common species / cumulative species list from T1 and T2 * 100.

Percentage accuracy

36 A number of species mis-matches will have resulted from the time elapsed between the surveyors recording and the QA assessment; these arise from management activities (crop harvesting, herbicide treatment, silage/hay cutting, hedge and verge cutting) and seasonal changes (die-back of early spring flowers e.g. *Arum maculatum, Ranunculus ficaria).* In addition, there will be instances of the QA plot being slightly mis-placed, and of the QA assessor overlooking species that are present. If these mis-matches are removed from the calculation then a new value of efficiency of initial recording is arrived at (Annex B).

37 Percentage accuracy = Common species / cumulative species list from T1 plus (T2 species minus T2 errors) * 100

38 In 2007 it was apparent that the recording of species on the list of common cryptogams (mosses, liverworts and lichens) was very inconsistent and was often depressing both the species richness and the number of ‘common’ species records, especially in the upland plots. In order to assess the impact of poor cryptogram recording on the overall species record the Percentage accuracy index has been recalculated for all plots omitting all cryptogam records (Annex B).

39 In CS it was clear that recording of cryptogams had a marked impact on the accuracy of the upland squares where bryophytes are often a major component of the vegetation whilst in the lowland squares, where bryophytes are less prominent, the increase in accuracy has been only modest. The Glastir QA exercise only covered 6 squares, of which only 1 was unenclosed upland, hence broader landclass comparisons are not possible. Perhaps at the end of the first phase of survey there will be a sufficiently large data set of QA squares to make these comparisons.

40 Annex B presents a summary of the % agreement and % accuracy for each of the 6 squares in the QA exercise.

41 A summary of these data by plot type forms Table 6. Only a single Arable and arable margin plot were recorded and this was misplaced by the Surveyors within the crop rather than within the cultivated margin. It might be expected that accuracy in the small ($4m^2$) U and Y plots would be depressed in comparison with the linear plots but this has not proved the case. For the U plots this may be largely explained by the relative homogeneity of the upland vegetation in which these are concentrated: a failure to precisely relocate the plot is likely to have a much lesser effect than for other plot types.

42 Percentage accuracy is slightly higher compared to the CS2007. Across all plot types the Glastir value was 66.8% compared to 62.2% for CS2000. Eliminating cryptogram species has made little difference to the Glastir results, rising to just 68.2% compared to 66.8% for CS2000. The greater efficiency is most apparent in the recording of boundary plots, only the small 'U' plots demonstrate a slight drop in efficiency of recording.

Table 6a. Summary of agreement by plot type.

CS2007 values for accuracy (excluding cryptogram) included for comparison.

Plot type	Number	% Agreement	% Accuracy	% Accuracy (-cryptogams)	CS2007 Accuracy (-crypto)
All	67	60.69	66.5	68.2	66.83
X	12	57.8	65.0	69.1	66.25
B	10	64.3	71.3	71.7	63.23
Y	9	56.2	64.1	66.4	64.27
H	9	62.9	66.1	68.4	67.74
U	6	59.3	66.8	68.1	76.91
S/W	10	62.6	66.0	67.0	69.44
P	10	62.3	68.1	68.9	

Table 6b. Summary of Glastir agreement by plot size. X ($200m^2$ plots), linear (10m x 1m plots, H, B, S, P) and small ($4m^2$ plots, U + Y)

Plot type	Number	% Agreement	% Accuracy	% Accuracy (-cryptogams)
All	67	60.6	66.5	68.2
X	12	57.8	65.0	69.1
Linear	38	62.7	67.5	68.4
Small	15	57.5	65.2	67.1

DISCUSSION.

GENERAL: RETAINED FROM CS2007 REPORT.

43 Problems associated with variations in accuracy rates in vegetation recording have long been appreciated, especially in the identification of grassland species (Ellison 1942; Hope-Simpson 1940; Smith 1944) but also in mire (Clymo 1980) and forest situations (Hall & Okali 1978).

44 Many long-term plot-based monitoring programmes rely on teams of surveyors, often with new teams being recruited for each repeat survey. This inevitably introduces variation in the data set, within and between years, due to differences in the surveyors' accuracy of species recording (Kirby *et al*. 1986; Prosser & Wallace 1992; Scott & Hallam 2002) and in their assessment of species cover (Kercher *et al.* 2003; Klimes 2003; Sykes *et al.* 1983) over and above genuine vegetation change.

45 Studies have used various measures to assess the level of mis-match between teams of surveyors. Within and between team sampling errors have been assessed using pseudo-turnover (Leps & Hadincova 1992; Nilsson & Nilsson 1985) which estimates the magnitude of species turnover due to recorder error above any natural change in species lists. It is based on the non-concordance of species in two lists collected in the same area at two different times, or by two different surveyors at the same time, expressed as a proportion of the total number of species recorded at each time. Nilsson & Nilsson (1985) found an average between-team pseudo-turnover of 13% for species lists from stands on small islands. Leps & Hadincova (1992) also report a turnover of 13% for two experienced observers recording 40 releves in 5m x 5m plots. A similar value (16%) can be calculated from the data of Hope-Simpson (1940) for chalk grassland plots. A rather higher value of 22% was found in small plots within a wide range of habitat types by Scott and Hallam (2002).

46 Other workers have approached the problem by considering the level of agreement between two lists; the number of common species is expressed as a percentage of the cumulative species list from the two records; reported values include a value of 83% for chalk grassland (Hope-Simpson 1940), a range of 32 to 80% for woodland (Kirby *et al.* 1986) and an average of 57% over a range of habitats (Scott & Hallam 2002). Prosser and Wallace (1992), as part of pre-CS1990 trial, reported average percentage agreements of 56% when two surveys were undertaken by different recorders, compared to 62% when the same recorders were used for both studies.

47 Where causes for differences in the lists are considered it seems that misidentification is relatively uncommon but the inability of surveyors to identify young plants and hence their omission from the record is probably often underestimated (Klimes, *et.al.* 2001). Similarly, surveyors with more field experience tend to overlook (omit) fewer species; the importance of training is emphasized (Smith 1944) as is care in the choice of surveyors (Oredsson 2000); Nilsson (1992) proposes that all vegetation analyses be based on teams of two investigators rather than a single recorder. Individual surveyors can thus have very different levels of survey accuracy; this may pose serious limitations in the use of such data sets for the assessment of changes in species diversity over time (Rich & Woodruff 1992; West & Hatton 1990).

48 The accuracy of plot relocation will also affect measures of species and community turnover (Prosser & Wallace 1992; West & Hatton 1990) and in this respect many authors have stressed the value of permanent quadrats (Bakker *et al.* 1996; Dodd *et al*.

1995; Herben 1996; Hill & Radford 1986). Klimes *et.al.* (2001) found a greater lack of concordance in smaller plots compared to larger quadrats.

SPECIFIC TO GLASTIR QA EXERCISE.

49 When mis-matches are expressed as a proportion of the total species record, the Glastir overall % agreement of 73.6%, based on the total species record of 1747, is comparable to the 1998 and 1990 QA exercises (73.1% and 79.3%) and higher than the CS2007 value of 65.6%. The range of % agreement values obtained on a plot by plot basis is similar to those from the previous QA exercises. The better recording of cryptogams in 2014 has probably assisted in the agreement scores for bryophyte-rich habitats.

50 Average % agreement values for individual squares (55.5% to 68.5%) are similar to previous QA exercises. Values were highest for the Boundary plots and lowest for the X plots. Some squares seem to produce consistently low scores (41349) whilst others were consistently good (12334).

51 The main factors affecting % agreement in Glastir were the overlooking of species and the appearance of seemingly random species records. The level of overlooked species was similar to CS2007 and higher than previous surveys, and may be attributable to the ever increasing number of tasks asked of the surveyors. This not only puts pressure on the time spent recording each plot once it is set up but often results in plots not always being searched by a pair of surveyors; or only partially surveyed by the pair such that species are missed. The increase in 'mystery' records seems best attributed to use of the tablets, but it is not possible to quantify. Since all plots were 'new' it is not surprising that location/orientation errors were low for the Surveyors.

52 % accuracy, taking account of mis-matches arising from the QA assessor, was very similar to CS2007. The main difference between the two surveys was in the accuracy of recording bryophytes. In 2007 removal of bryophytes from the species record substantially increased the % accuracy of the upland squares from 59% to 71%. In the lowland grassland and marginal upland land classes the differences were much less. In the Glastir survey there was little increase in % agreement through removal of bryophytes (66.8% to 68.2%) partly reflecting the generally lowland nature of most of the QA squares.

RECOMMENDATIONS.

53 *Plot relocation.* Many of the issues relating to plot relocation resulted from inaccurate measurements and compass bearings such that many plots were only approximately relocated and orientated. It was not always clear if a tape or range finder had been used. For accurate plot relocation over a distance of <50m there should be a presumption of using a tape. The lack of sighting compasses resulted in impossible triangulation issues. It is recommended that sighting compasses be provided to each team and also that the technique of lining up series of distance objects be considered where plots are >50m from a boundary or any other feature. When using the compass always stick to recording magnetic north, rather than making corrections which are often inaccurate. Some sketches needed considerable interpretation - more training on 'good' sketches. Usually the simplest are the best - not works of art. Often a seemingly small and insignificant feature may be very useful once one is close to the plot.

54 *dGPS*. All the QA exercise was carried out without the use of dGPS. In past QA trials the assessors used a metal detector to good effect in re finding metal plates and thus providing greater confidence that plots had been accurately refound. Since the repeat survey will be assessing change it is important to ensure that relocation errors are kept to a minimum. It would seem imperative that a proper trial be carried out to test the efficiency of using the Trimble for plot relocation. To achieve this an example square needs to be visited, plots set up and sketches and photos taken. A metal plate needs to be buried at the same point that the dGPS is used to 'Stamp' the plot. A second team then needs to return to the square and set up the plot using (a) dGPS alone (b) sketches and photos alone, (c) combination of sketches, photos and dGPS and finally (d) find the metal plate using a metal detector. An assessment of the distance discrepancies between the different methods can then be made.

55 *Plot positioning.* More training on where the individual plots go, especially relative to each other. Hedge plots were consistently put in the wrong place, and rarely linked to boundary plots on sketches and usually placed at one end of the 'D' plot.

56 *Grasses*. Need for more practice in vegetative ID during training courses.

57 *Photos*. Emphasise importance of photographs – do not take close-ups of plots if poorly illuminated; include salient background features; always indicate position of photo on plot sketch.

58 *Tablet.* Default for ‘presence’ cover value in the ‘selected species’ table to avoid lengthy data inputting

59 *Species cover values.* Assess this once more squares have been surveyed.

60 *Tablet.* Needs an intelligent system for typing in and recognising additional species from the long list. The keyboard tab could be used to input the first 3 letters of the generic name and first 3 letters of the species name thus providing a short list (or a unique ID) for the target species which can then be selected. Urge surveyors to be patient when inputting - take time to ensure correct species has been recorded from the drop down menu. Partner to recall previous records to avoid over writing records. More effort to record as pairs and always call out species as recorded else species will be missed by both assuming the other has recorded it.

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Annex A. List of squares surveyed.

Square	Team	Survey date	QA date
12334	Mid	03/09 - 05/09/2014	09 /09 - 10/09/2014
12768	Mid	21/08 - 25/08/2014	27/08 - 29/08/2014
14994	South	17/07 -21/07/2014	23/09 - 24/09/2014
18367	South	22/07 - 24/07/2014	6/08 - 8/08/2014
36931	North	7/07 -11/07/2014	21/07 -23/07/2014
41349	North	16/06 -18/06/2014	30/06 - 2/06/2014

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	T1	T2	Total	Common	A	B	C	D	J	E	F	G	I	% Agreement	% Accuracy
12334	X1	36	44	44	35		5						4		79.5	87.5
12334	X3	25	24	30	20	4	3		2				1		66.7	69.0
12334	Y2	22	23	28	16		6		1				3	2	57.1	69.6
12334	S1	34	42	45	28	4	10		1				2		62.2	65.1
12334	S2	41	41	49	34	2	7		5					1	69.4	70.8
12334	P1	32	33	38	28		6		1				3		73.7	80.0
12334	P2	18	20	21	15	2	1		2				1		71.4	75.0
12334	U5	11	12	14	9		2						3		64.3	81.8
12334	U9	17	15	19	13		2		2				1	1	68.4	76.5
12334	U10	15	16	18	13	2	2						1		72.2	76.5
															68.5	
12768	X1	26	29	33	22	2	5		1					2	66.7	71.0
12768	X2	23	28	30	21		5					1	2	1	70.0	80.8
12768	B1	27	27	31	23		2						4	2	74.2	92.0
12768	B2	23	29	32	20		9		1					2	62.5	66.7
12768	H1	10	18	19	9		9							1	47.4	50.0
12768	H2	21	20	23	18	2	1	1						1	78.3	81.8
12768	Y2	10	11	15	5	4	3		2				1		33.3	35.7
12768	S1	28	33	40	25		10	1	1				1	2	62.5	67.6
12768	W1	40	47	51	34	4	9		1					3	66.7	70.8
12768	P1	27	23	32	18	2	4		2				1	5	56.3	69.2
12768	P3	34	35	43	25	4	7		1				2	4	58.1	67.6
12768	U1	19	17	23	13	2	3		3					1	56.5	59.1
															61.0	
14994	X3	31	34	40	25	2	6		2			1	2	2	62.5	71.4
14994	X4	19	18	22	15		3		2			1	1		68.2	75.0
14994	B3	17	22	26	13		8		1				1	3	50.0	59.1
14994	B4	26	23	28	21		2		1		1	1		2	75.0	87.5
14994	H1	15	23	24	14	2	6						2		58.3	63.6
14994	H2	23	25	30	18	2	6		2					2	60.0	64.3
14994	Y1	18	20	24	14		5		1			1	3		58.3	70.0
14994	Y2	15	13	18	10		2		1		3		1		55.6	71.4
14994	S1	27	23	29	21	2	1	2	2			1			72.4	75.0
14994	P1	18	21	23	16	2	4							1	69.6	72.7
14994	U1	10	12	16	6	2	4						4		37.5	50.0
14994	P2/S2															
															60.7	

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	T1	T2	Total	Common	A	B	C	D	J	E	F	G	I	% Agreement	% Accuracy
18367	X2	31	27	36	23	2	3		3				2	1	63.9	69.7
18367	X4	24	16	28	13		3		4			5		3	46.4	65.0
18367	B2	17	26	27	16		10		1						59.3	59.3
18367	B4	14	15	16	14		1							1	87.5	93.3
18367	H1	24	29	32	20	2	7	2	1						62.5	62.5
18367	H2	25	26	32	19	2	6	2	1					1	59.4	61.3
18367	Y2	10	13	15	8		4						3		53.3	66.7
18367	W1	14	21	27	8	2	5			11				1	29.6	30.8
18367	W2	23	23	28	18	2	4		1				1	2	64.3	72.0
18367	P3	17	18	22	13		5		2	1				1	59.1	61.9
18367	P4	13	14	17	10		4	1	1				1		58.8	62.5
18367	U1	17	26	28	16	2	9		1						57.1	57.1
															58.4	
36931	X4	21	24	28	17	2	4						2	3	60.7	73.9
36931	X5	16	22	24	13	1	5		2				2		54.2	59.1
36931	B4	18	20	27	11	4	7	1	2			2			40.7	44.0
36931	B5	22	25	29	19		6						1	3	65.5	76.0
36931	H1	14	15	15	14		1								93.3	93.3
36931	H2	16	18	22	12	2	5		1			1		2	54.5	63.2
36931	Y2	11	11	15	7		3		2				3		46.7	58.3
36931	Y3	8	9	9	8		1								88.9	88.9
36931	W1	28	33	39	22	4	8	1	1			1		1	56.4	59.5
36931	P1	24	27	34	18	2	9		1			1		3	52.9	60.0
															61.4	
41349	X3	11	14	18	7	2	5		1				1		38.9	41.2
41349	X4	2	5	6	1	2	3								16.7	16.7
41349	B3	17	17	19	15	4	2								78.9	78.9
41349	B4	12	15	18	9	2	5							2	50.0	56.3
41349	H1	17	15	21	11		4	2	3					1	52.4	55.0
41349	Y1	14	18	21	11	2	5							1	52.4	55.0
41349	Y2	17	20	23	14	1	4	1							60.9	60.9
41349	S3	26	26	29	23		3	2				1			79.3	82.1
41349	W1	15	21	22	14		7							1	63.6	66.7
41349	P2	15	15	18	12		3	1	2						66.7	66.7
41349	P3	17	19	23	13		6						2	1	56.5	65.0
41349	B2															
41349	A4	12	17	22	11		10							1	50.0	52.4
															55.5	
				1748		86	325	17	68	12	4	17	62	67		
															66.1	66.6

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	Location	adequate	How arrived at	Sketch	Photo
12334	X1	within 1m	y	Sketch and photo	Good use of nearby features	Good
12334	X3	Close	y	Sketch and photo	Good use of nearby features	Adequate
12334	Y2	Close	y	Sketch and photo	not enough local detail	Not sufficient
12334	S1	within 2m	n	Sketch and photo	Measurements didn't all tally	good
12334	S2	within 0.5m	y	Sketch and photo	lacked vital plot bearing	OK
12334	P1	Close	y	Sketch and photo	Simple but needed photo to work	OK
12334	P2	Close	y	Sketch and photo	Needed more distances/bearings	OK
12334	U5	Close	y	GPS + photo	Lacked features (but there weren't many)	Essential
12334	U9	Close	y	GPS + sketch	Photo essential combined with sketch	OK
12334	U10	Close	y	GPS + sketch	Adequate	OK
12768	X1	within 2m	y	Sketch and photos	Poor, needed careful reinterpretation	Helped
12768	X2	?	n	Sketch and photos	Distances too great for accuracy	No use
12768	B1	Within 1m	y	Sketch and photo	Poor, Misleading from X plot	OK
12768	B2	Precise	y	Sketch and photo	Good	Good
12768	H1	Precise	y	Sketch and photo	Location re B1 incorrect and not given	
12768	H2	Precise	y	Sketch and photo	Good - linked to X2 and B2	Good
12768	Y2	OK	y	Sketch and photo	Good	OK
12768	S1	Precise	y	Sketch and photo	Good	Good
12768	W1	0.5m	y	Sketch and photo	Needed photo for clarification	Good
12768	P1	Close	y	Sketch and photo	OK	Good
12768	P3	Precise	y	Sketch and photo	Good	Good
12768	U1	Good	y	Sketch and photo	Good	Good
14994	X3	Close	y	Sketch and photo	OK	OK
14994	X4	Close	y		Poor, need to key in boundary then set out X	
14994	B3	Precise	y	Sketch and photo	OK	OK
14994	B4	Precise	y		Relies on finding X from compass bearings	Needed
14994	H1	Precise	y	Sketch and photo	Fine	OK
14994	H2	Precise	y	Sketch and photo	Fine	
14994	Y1	Uncertain (within 2	n		Features too imprecise, ? Tape or range finder	
14994	Y2	Uncertain	n	Photo	Needed distance along fence then distance out	
14994	S1	Precise	y	Sketch and photo	Good	Good
14994	P1	Precise	y	Sketch and photo	Good	Good
14994	U1	within 2m	y	Sketch and photo	Good	Good
14994	P2/S2	Impossible to find	y		Needed info for access	

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	Location	adequate	How arrived at	Sketch	
18367	X2	>3m out	n	Sketch and photo	Long distances on bearings. ?Range finder or tape.	Essential
18367	X4	Close	y	Sketch and photo	Too much extra information but essentials there OK	
18367	B2	Precise	y	Sketch and photo	Distances not clear on map, 59m but 1.6m caused confusion.	Essential
18367	B4	Close	y	Sketch and photo	OK	OK
18367	H1	Close	y	Sketch and photo	OK	OK
18367	H2	Precise	y	Sketch and photo		
18367	Y2	Close	y	Sketch and photo	Measurements didn't match photo so adjusted	Essential
18367	W1	Close	y	Sketch and photo	OK but nearer features available to measure from	
18367	W2	Precise	y	Sketch and photo	Distances not clear on map, 1.6 looked like 16	Essential
18367	P3	Close	y	Sketch and photo	Out since W1 was out	
18367	P4	Close	y	Sketch and photo	Taken from outside fence as in diagram	
18367	U1	Close	n	Sketch and photo	OK	Essential
36931	X4	Approximate	n	Sketch and photo	Needs 1 actual measurement	
36931	X5	Approximate	n	Sketch and photo	OK	
36931	B4	Precise	y	Sketch and photo	Easy to refind	Good
36931	B5	Precise	y	Sketch and photo	Easy, but better features could have been used	Good
36931	H1	Precise	y	Sketch and photo	Poor. Seems H1 is at one end of D1	
36931	H2	Precise	y	Sketch and photo	OK	OK
36931	Y2	Approximate	n	Sketch and photo	Poor.	OK
36931	Y3	Precise	y	Sketch and photo	Good	Good
36931	W1	Close	y	Sketch and photo	Not precise enough re features	
36931	P1	Close	y	Sketch and photo	No bearing for orientation	
41349	X3	Close	y	Sketch and photo	Poor for finding B that it links to	
41349	X4	Close	y	Sketch and photo	Too much info! Access confusing- metal gate not accessible	
41349	B3	Close	y	Sketch and photo	No link to the H and D which are measured along the boundary	
41349	B4	Close	y	Sketch and photo	Too much info! Access confusing- metal gate not accessible	
41349	H1	Close	y	Sketch and photo	Wrong place should be 25m from B3	OK
41349	Y1	Close	n	Sketch and photo	Good	
41349	Y2	Close	y	Sketch and photo	Good	Good
41349	S3	Close	n	Sketch and photo	Too much info but not most useful!	useless
41349	W1	Precise	y	Sketch and photo	Good	Good
41349	P2	Precise	y	Sketch and photo	Good	Good
41349	P3	Close	y	Sketch and photo	Too much info but not most useful!	
41349	B2		y		Not QA'd but in a very strange place	
41349	A4		y		Doing into the crop as they did. If compared the correct crop edge the result would	

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	Orientation
12334	X1	Dubious
12334	X3	Dubious
12334	Y2	Dubious
12334	S1	Difficult water edge to follow - more comments needed
12334	S2	
12334	P1	OK
12334	P2	Bearing needed extra measurement on diagram
12334	U5	
12334	U9	
12334	U10	
12768	X1	Measurements didn't converge
12768	X2	Poor: didn't converge
12768	B1	Difficult hedge on ditch:precise position unclear
12768	B2	
12768	H1	Exact location re ditch/hedge unclear, v. difficult to access
12768	H2	
12768	Y2	Not precise
12768	S1	River low so exact bounds of plot unclear
12768	W1	
12768	P1	Compass bearing seemed wrong
12768	P3	OK
12768	U1	OK
14994	X3	Photo and compass bearings don't tally
14994	X4	Compass bearings didn't tally with measurements, had to adjust by 6m to get Urtica in cell 1 not cell 4.
14994	B3	Impenetrable nettles and brambles by September
14994	B4	? Distances using tape or range finder
14994	H1	Wrong location re X. Also at end of D not in middle
14994	H2	Again H at end not in middle of D. Not sure how it relates to an X plot.
14994	Y1	Didn't converge
14994	Y2	Too many features with range finder but not taped. Didn't converge
14994	S1	
14994	P1	
14994	U1	8 degrees out from measurement based on photo
14994	P2/S2	General comment for square is sketches don't link plots adequately and don't always provide useful measurements

Annex B. Glastir 2014. Sources of error and plot relocation issues

Square	Plot	Orientation
18367	X2	Plot didn't tally with photo, had to move plot >2m, still not a good match. Bearings didn't converge
18367	X4	Uncertain: a lot of mismatched species.
18367	B2	
18367	B4	
18367	H1	Hedge at end of D plot not in middle
18367	H2	
18367	Y2	Needed photo for relocation
18367	W1	Plot misplaced at T1 at top of bank
18367	W2	Position relative to fence suggests it straddles fence line - I would have gone entirely ditch side of fence
18367	P3	Should have had zone 0 down bank but followed their sketch all at top
18367	P4	2 zones recorded but no distances on plan
18367	U1	Measurements then adjusted from Photo.
36931	X4	Approximate distances and bearings don't allow accurate positioning
36931	X5	Not precise, measurements and bearings don't tally
36931	B4	
36931	B5	OK
36931	H1	Again, H at one end of D
36931	H2	
36931	Y2	Distances and bearings converge but plot in wrong place!
36931	Y3	Fine
36931	W1	Measurements and bearings don't tally. Adjusted to follow their sketch
36931	P1	Diffuse ditch edge, difficult to determine precise plot start
41349	X3	
41349	X4	Arable field
41349	B3	
41349	B4	
41349	H1	Again, H at end of D not in middle. Surveyors not far enough into hedge
41349	Y1	Not exact match
41349	Y2	Good
41349	S3	
41349	W1	OK
41349	P2	OK
41349	P3	No bearing
41349	B2	
41349	A4	In wrong place, 1m into the crop rather than along the ploughed margin

GMEP Bird Survey Methods

Introduction
The spring GMEP bird surveys are designed to reveal associations between breeding bird locations and Glastir management, as well as population changes in response to that management. However, there are several Glastir options that aim to enhance habitat for farmland birds in winter and that are likely to be critical for granivorous farmland birds in arable farmland. While the breeding season surveys should provide a means for testing the ultimate impacts of winter management, attribution of changes to the mechanism of winter food resource provision and success of that management per se (i.e. does it attract target species?) require specific monitoring in winter.

Currently, winter habitat effects on bird abundance are known to be important in arable farmland, but there is not such clear evidence for other habitats and no Glastir options for other habitats. Hence, winter bird surveys are a priority only in the arable parts of Wales. Surveys will therefore be conducted only on arable and mixed farms.

Specifically, the arable components of GMEP survey 1km squares (including the grassland elements of mixed farms) will be surveyed in one or more winters (resources permitting) between the first and second breeding season in which the squares are surveyed for breeding birds. Few 1km squares in Wales can be considered to be dominated by arable habitats, so an inclusive approach will be taken in which all squares with 20ha or more of arable land-use will be covered. The survey methods will follow those used in other surveys of wintering farmland birds. Analyses will investigate the use of Glastir management options by birds relative to background wintering bird populations in arable farmland.

Methods
The survey approach will consist of two visits, one in December and one in January, in which the surveyor walks a route along all field boundaries within the arable areas of each GMEP square and conducts whole-area search surveys of seed-rich habitats, including stubble fields, game cover crops and relevant Glastir options. Routes will also incorporate any grass fields present in the square that are part of the same farm as the target arable fields. Bird locations will be mapped with respect to habitat patches (fields, hedges, other habitats) and all birds seen and heard will be recorded.

Detailed methods will be as follows:

- The aim is to record all birds in the arable land in the square, or in all fields (arable and grass) in mixed farms, noting location and behaviour of all birds on each visit. A3 maps of the survey squares (use at least one per survey visit) and clipboards will be provided.
- Make two visits to each square, one in each of December and January.
- Access will be available to all arable parts of the square, or the square will be omitted from the sample.
- Visits can begin at any time, but should avoid the half hours after sunrise and before sunset. Avoid bad weather (rain, high winds) that is likely to affect counts or detection.
- Record weather conditions on each survey map: precipitation (none, intermittent, light and persistent), temperature (approximate), percentage cloud cover and Beaufort wind speed. Record conditions at the start and at the end of the survey (precipitation at the end of the survey should consider the whole survey period).

- Walk along all field boundaries, or within 50m of each point within the square (e.g. “transect” lines no more than 100m apart) in seed-rich habitats (stubbles, bird covers, Glastir option patches).
- Record all birds seen and heard using standard CBC notation, using BTO two-letter species codes and the relevant activity codes. Although we are fundamentally only interested in birds within the square boundary and only the area within the boundary needs to be covered (i.e. ideally routes do not need to pass closer than 50m of the boundary), record birds just outside the boundary as well as they are encountered.
- Most surveys should take less than three hours, but the exact time will depend on the size of the surveyable arable area and the habitat/bird density. Two-three surveys should be possible per day, depending on distances between squares.
- Record the exact survey route followed on a map and highlight areas considered poorly covered or not covered. For example, an open area of 200m across with survey routes along either edge might be considered “poorly covered” if it could be scanned from the boundaries such that large species can be seen but small ones not flushed, whereas a similarly-sized woodland with no access to the interior would probably best be considered as “not covered”. Surveyors should use their judgement here as this variable will depend on subtle, local features, such as topography and vegetation height. Recording and standardizing route coverage (where surveyors actually walk) is more important than standardizing the exact order in which areas are covered.

Farmers and Local Authorities Perceptions of Glastir:

A Qualitative Evaluation of Glastir Woodland Creation and Management Schemes

[1]Kate Walker-Springett & [2]Dr Karen A. Parkhill
[1] k.walker-springett@bangor.ac.uk [2] k.parkhill@bangor.ac.uk

School of Environment, Natural Resources and Geography, Bangor University

On behalf of the Glastir Monitoring and Evaluation Project

August 2014

Llywodraeth Cymru
Welsh Government

Canolfan Ecoleg a Hydroleg
CYNGOR YMCHWIL YR AMGYLCHEDD NATURIOL
Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

PRIFYSGOL BANGOR UNIVERSITY

Executive Summary

This research was commissioned to investigate and better understand the farmers' and Local Authorities perceptions of the challenges and benefits of the Glastir Woodland Creation (WC) and Woodland management schemes (WM). Qualitative methods were used in this research; focus groups with member of the farming community from a range of farm types and sizes took place at four locations across Wales. Telephone interviews with Coed Cymru officers within Welsh Local Authorities were also conducted.

Uptake of the Glastir WC and WM elements has been lower than expected triggering a concern that the Welsh Government target of 100,000 ha of new woodland to be created by 2030 might not be met. Previous research indicates that there are a number of barriers for farmers (key landowners in Wales) in terms of creating woodlands including: conflict between the land required for food production and that for woodland creation: and, a perceived division between the forestry and agricultural, particularly in terms of skills and knowledge sectors and economic disincentives. Little prior research has focussed on the engagement of Local Authorities in Glastir schemes.

This research finds little evidence to support the notion of a division between agriculture and forestry; contrary to the literature famers across Wales appear to be open to woodland creation and appreciate the numerous on and off-site benefits associated with increased tree numbers. However, significant barriers exist in the form of the Glastir scheme process. The process is perceived to undermine the scheme objectives and acts as a disincentive for potential scheme member from both the farming community and Local Authorities. It is recommended that four key elements be further investigated and adapted in order to encourage greater scheme uptake:

- The complex nature of the scheme (for example operation prescriptions for size and width of woodland, and the application process) needs to be simplified.
- The scheme is perceived as being inflexible (for example not allowing postponement of activities due to weather conditions) and therefore needs to be more flexible to take account of unexpected influences.
- The auditing process is complex and includes penalties (for example withdrawal of Glastir payments) and therefore penalties need to be clearer and the auditing process part of the scheme needs to be less threatening.
- Payment rates are obscure (for example there is confusion about what is covered and rates for contractual labour are not included) and therefore these need to be made clearer.

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Acknowledgements

This research would not have been possible without the participation of members of the farming community and Coed Cymru officers across Wales

1.0 Introduction

There is a significant amount of literature, both in the form of government documents and research outputs (e.g. reports and journal articles), which demonstrate the benefits of woodland creation (Nijnik and Bizikova 2008; Osmond and Upton 2012; Valatin and Saraev 2012; Wynne-Jones 2013a; The Woodland Trust. n.d.). It is accepted that trees provide habitat for wildlife, thereby increasing the biodiversity in a given area; this is of particular relevance in an agriculture setting where habitat heterogeneity is reduced (Altieri 1999). The Pont Bren project illustrates the benefits trees can have in improving upland hydrology, which has downstream implication for flood prevention and mitigation as well as on site benefits (The Woodland Trust. n.d.). Trees can provide a sustainable source of fuel and resources, which can in turn lead to economic gains, dependant on external factors such as market forces and size of plantation. More recently, tree planting has been increasingly prioritised as a way to sequester carbon and offset emission from carbon intensive activities (e.g. flying and agriculture – see Osmond and Upton 2012). With these benefits in mind, and in combination with the need to offset the emissions from the Welsh agricultural sector in order to meet the annual year-on-year carbon reduction target of 3%, in 2010 the Welsh Government accepted recommendation from the Welsh Land Use and Climate Change Group to increase the area of woodland in Wales by 100,000 ha (a 33% increase), by 2030.

In order to meet the 100,000 ha challenge, it was recommended that financial incentives should be put in place to encourage landowners to plant trees. One such financial mechanism is the Glastir Woodland Creation (WC) and Woodland Management (WM) schemes. Both WC and WM sit within the broader Glastir agri-environment scheme the aim of which is to continue and build upon the environmental and conservation focus of previous schemes within Wales, such as Tir Gofal (Wynne-Jones 2013a). Glastir WC and WM are stand-alone elements meaning that they are open to landowners in general and there is no requirement to be part of the larger Glastir scheme. For those within the wider Glastir element, woodland creation and management options are also available as part of the higher-level component of Glastir entitled Glastir Advanced. The Glastir scheme is funded through Axis 2 of the Rural Development Fund, as part of the EU Common Agricultural Policy.

The shift in focus from woodland creation on state owned land in the post Second World War period, to privately owned land means that incentive schemes such as Glastir are a primary method of achieving environmental goals, given that 80% of the land in Wales is farmed (Osmond and Upton 2012). However, physical (e.g. availability of land) and attitudinal (e.g. perceptions of woodland) barriers exist within the agricultural sector that leads to lower than expected uptake of woodland creation schemes (Lawrence et al. 2010). Previous research indicates that the attitudes of farmers play an important role in the decision to take up incentive scheme for woodland creation (Lawrence et al. 2010) as well as socio-demographic factors such as farm type, size and age of farmer (Lawrence et al. 2010). In addition, there is a paucity of research that investigates the efficacy of agri-environment schemes outside the agricultural sector. For example, Local Authorities (LAs) across Wales are responsible for woodland and have been also identified by Welsh Government as key participants for the Glastir WM and WC schemes. The interaction of LAs with Glastir WM or WC schemes to help finance woodland management and creation, which might not otherwise occur, is an important consideration when assessing the success of these schemes.

In Wales, Glastir and it predecessors Better Woodland Wales and Tir Gofal led to the creation of 1102.3 ha of new woodland between 2010 and 2012, representing just 1.1% of the overall 100,000 ha target (Wynne-Jones 2013a). Irrespective of the 100,000 ha target, the lack of uptake also had, and to continues to have, serious consequences on the provision of the range of environmental benefits expected as a result of the creation of new woodland and the appropriate management of existing woodland. Many stakeholders feel that the 100,000 ha target is unachievable in its current format (Wynne-Jones 2013a); if the target was number of trees rather than the area of woodland, it would perhaps be more realistic, since, for example, it would be able to take into account tree in hedgerows (Osmond and Upton 2012). Overall, greater levels of support and an integrated approach have been suggested as a way to merge farming and forestry in order to encourage the farming community to help achieve the tree planting targets (Wynne-Jones 2013a). However, integration and support can only occur if the underlying barriers and attitudes of the agricultural sector and beyond are fully understood.

The established body of research indicates that attitudes towards woodland on farms are a complex, interlinked and dominated by several key factors, which have been outlined below.

General Attitudes towards Forestry

Farming culture: Farmers hold agricultural landscapes in high regard, and social status within the farming community is achieved through good farming practice (Bell, 1999, Burton and Wilson, 2000). The conversion of productive agricultural land into woodland is seen as being morally wrong; food production takes precedence and in general woodland should be planted on land that cannot be farmed (Bell, 1999).

Timescales: The length of time taken for woodlands to mature means that land converted to woodland is less reactive to changes in markets, in comparison to crops or livestock based agriculture (Burton and Wilson, 2000; Silcock and Manley, 2008).

Socio-demographic factors

Age: Younger farmers have been shown as more likely to plant woodland (Gasson and Hill, 1990), possibly explained by the perception that land converted to woodland is a long term land use change and the increased likelihood that a younger farmer will see a financial return from his or her investment in woodland (Watkins et al., 1996).

Suitable Land: A common reason for farmers not planting trees is lack of suitable land (Watkins, 1984) and smaller farms are have been shown to be less likely to take up grants focussed on tree planting (Wavehill Consulting, 2009).

Woodland Grants

Uses: Participants in grant schemes for woodland creation have been shown to actively use their woodland, in comparison to those not involved in such schemes. The main reasons for woodland creation are: recreation, conservation and developing livestock shelters and field boundaries (Wavehill Consulting, 2009).

Efficacy: The evidence related to the efficacy of grant in encouraging woodland creation and management is not clear. It is also difficult to tell whether grants do really encourage new woodland creation or whether the landowners would have planted the trees anyway (Watkins, 1984; Sharpe et al., 2001; Church and Ravenscroft, 2008).

Uptake: Barriers exist to grant uptake which are distinct from attitudes towards forestry. These include perceived scheme bureaucracy, complex application process and lack of knowledge about available grants (Crabtree et al., 1998; Ward and Manley, 2002; Cunningham, 2009; , Wavehill Consulting, 2009).

For a more comprehensive review of the available literature, please see the Literature Review in Appendix A.

Aims and Objectives

The aim of this report is to investigate and better understand the farmers' and LAs perceptions of the challenges and benefits of the Glastir Woodland Creation and Woodland management schemes. Using qualitative methods the project has two objectives:

1. To investigate attitudes (positive and negative) towards both the Glastir Woodland Creation scheme and the Woodland Management scheme by Welsh farmers, and identify barriers to help explain the low rate of uptake, as well as possible opportunities to encourage uptake.

2. To investigate the attitudes (positive and negative) of Welsh Local Authorities to the Glastir Woodland Creation Scheme and the Woodland Management scheme, and identify barriers to uptake, as well as possible opportunities to encourage uptake.

2.0 Methods

This study incorporated two distinct methods, focus groups and interviews, to explore attitudes and opinions towards the Glastir Woodland Creation and Management Schemes within the farming community and Local Authorities across Wales. Focus groups were used to encourage reflection and discussion with members of the farming community. The aim of focus groups is not to be representative in the statistical sense, rather generalisability is possible by ensuring that range of viewpoints are captured due to the sampling techniques and criteria used to select participants, and through careful interpretations aided by research and conceptual literature. Telephone interviewing as a methodology allows a greater quantity of interviews to be carried out within the time available, given the geographic spread of interviewees. As with the focus groups, this methodology allowed a wide range of views to be captured, again allowing generalisations to be formulated. We would anticipate that the findings outlined in this report would have broad resonance with the wider farming community and Local Authorities involved in WC and WM schemes not part of this research. Prior to inviting any participants, the outline plan for the focus groups and all associated materials were approved by the Bangor University Ethics Panel. The Glastir Monitoring and Evaluation Programme Team also approved both the overarching project plan and all outgoing external communications.

2.1 Focus Groups

In order to sample as wide a range of the Welsh farming community as possible, focus groups were carried out across Wales. Priority areas were identified, with the assistance of Welsh Government, as being East Wales/Welsh Marches, East Powys, and the Severn Valley catchment due to forthcoming woodland creation geographical targets. This led to four focus groups being held in Bangor, Newtown, Abergavenny and Wrexham (Figure 1); in total, 22 individuals participated.

Figure 2.1: Map showing of the locations of the four focus groups held with members of the farming community and the 14 Welsh Local Authorities where the incumbent Coed Cymru officer was interviewed.

● = focus group locations: Bangor, Wrexham, Newtown and Abergavenny

'Demographic' criteria impacts upon peoples' worldviews, this in turn has an impact on peoples' attitudes. In this study, using previously published literature farm type and farm size were identified as being important criteria. Using the annual farm survey from June 2010 in combination with agri-environment scheme membership, farmers within 20-mile radius of each focus group location were targeted. Initial contact was made by letter and follow-up phone calls were made to confirm attendance, ensuring that a range of farm typologies (sizes and scheme memberships - i.e. current and historic agri-environment or woodland creation schemes) were included. The sample was broadly representative of the type and size of farms across Wales (Table 1).

	Focus Group			
	Bangor	Abergavenny	Newtown	Wrexham
Scheme Membership[1]				
S_NG	1	2	1	0
S_GE	2	3	1	1
S_GA	0	1	1	0
NS_NG	0	0	0	4
NS_GE	1	0	0	0
NS_GA	2	2	0	0
Farm Type[2]				
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	1	-	3
5	-	1	-	1
6	5	2	2	-
7	-	1	-	1
8	-	-	1	-
9	1	3	-	-
Farm Size (SLR)[3]				
0	-	1	-	-
1a	1	2	1	1
1b	2	-	1	1
2	1	1	1	-
3	1	2	-	-
4	-	2	-	-
5	1	-	-	3

Table 2.1: Demographics of focus group participants, obtained from June 2010 Horticultural Survey (DEFRA, 2010) and Glastir Scheme Membership data.

[1]Scheme Membership: S_NG: Previous agri-environment scheme, but not in Glastir; S_GE: Previous agri-environment scheme, currently in Glastir Entry; S_GA: Previous agri-environment scheme, currently in Glastir Advanced; NS_NG: No previous scheme, not in Glastir; NS_GE: No previous scheme, currently in Glastir Entry; NS_GA: No previous scheme, currently in Glastir Advanced.

[2]Farm Type - 1 = Cereals; 2 = General cropping; 3 = Horticulture; 4 = Specialist Pigs; 5 = Specialist Poultry; 6 = Dairy; 7 = LFA Grazing Livestock; 8 = Lowland Grazing Livestock; 9 = Mixed; 10. Other

[3]Farm Size (SLR) – Standard Labour Requirement (SLR) is a measurement of farm size, taking into account difference in the labour needed across different agricultural sectors. One SLR equates to 1900 working hours per year.
<1 SLR = Very Small
>=1 and <2 SLR = Small
>=2 and <3 SLR = Medium
>=3 and <5 SLR = Large
>5 SLR = Very Large

Each focus group began with an introduction to the project and participants were asked to sign consent forms, acknowledging the fact that the focus group was being audio recorded for the purpose of later being transcribed in preparation of thematic analysis. The main part of the focus groups were comprised of three sections. The first encouraged participants to discuss attributes of good and bad farming practice. The second explored the relationship Welsh farmers have with the environment. Finally, questions surrounding Glastir and the impact this had on perceptions of the environment were discussed, both in the context of woodland and the broader sense of general agri-environment schemes.

The discussion within section one began to identify opinions about Glastir and also gave context to explain ideas and opinions that were subsequently revealed in sections two and three. The second section used four images of different landscapes to explore perceptions of forested and un-forested scenes. Participants were encouraged to explain how they felt about each scene and discuss as to whether the scenes would fit in with their farming practices (Table 2). Using the photographs, this section probed perceptions associated with different woodland landscapes in order to identify underlying opportunities and barriers towards and uses of woodlands on agricultural land.

Agricultural Scene	Woodland Scene	Shelter Scene	Unmanaged Woodland

Table 2.2: Landscape photographs used in the focus group to compare attitudes to different woodland scenes.

Finally, the third sections used statements derived from Wynne Jones (2013a) and Osmond & Upton (2012) to explore commonly held association of farmers and forestry (Figure 2). Concepts such as the space and time needed to plant and manage woodlands, the potential uses and revenue sources and the increased need for food security where among the themes probed, as such section three concentrated the discussions on woodland on agricultural land.

Planting woodland on my farm would have many benefits, for example: timber production, creating habitat for wildlife and helping to manage flooding. Most farmers have small pockets on unproductive land which could be converted into woodland.

My choices about what to do on my land revolve around how to add value. I don't see how planting trees can really pay - the financial incentives are not large enough.

I wish I had planted the woodland years ago, it's a lovely place to walk the dog, plus we coppice and use the wood for fuel at home. Planting woodland reduces the carbon footprint of the farm and stops us being so reliant on imported fuels.

Farmers are farmers, not foresters - I don't feel I have the knowledge or the skills to plant and manage a woodland; I don't know who to turn to for help or advice.

There is such an increased demand for food which will increase in the future, that taking land out of production for tree planting is not viable. I would not have the time to manage woodland either, with all the other demands on my time.

The time period that you are tied in for with woodland creation is too long. I don't know what will happen to my farm in the future so I would prefer to be able to have more control of my land now.

Figure 2.2: Statements used in focus groups to facilitate discussion around farmer's perceptions of woodland.

2.2 Interviews

Telephone interviews were conducted with Coed Cymru officers from a range of the Welsh Local Authorities (LA) that have responsibility for woodlands. Initial contact was made through email, with follow up calls to arrange a suitable time. At the beginning of the telephone interview, a brief introduction to the project was given, and the interviewee gave verbal consent of the conversation to be recorded for transcription. The interviews then explored attitudes and opinions of the Glastir Woodland Creation and Woodland Management schemes, from the perspective of the Local Authority. In total, nine interviews were conducted covering the following Local Authorities: Anglesey; Carmarthenshire; Ceredigionshire; Conwy; Denbighshire; Gwynedd; Neath, Port Talbot and Swansea; Wrexham; and Rhondda, Bridgend and Merthyr Tydil (Figure 1).

3.0 Results and Discussion

3.1 The Glastir Scheme

This research set out to use qualitative methods to unpack the attitudes towards the woodland elements within Glastir, focussing on both the farming community and Local Authorities via Coed Cymru officers. Discussions with members of the farming community revealed that thee was little separation of the Glastir Woodland Creation and Management schemes from that of Glastir as a whole. With this in mind, the attitudes and opinions expressed reflect both the experiences participants had with Glastir in general, and it was impossible to always isolate only those attitudes that related to the WC and WM strands. Within the Local Authorities, perhaps because some of the Coed Cymru officers interviewed have been or currently are advisors for the WM and WC schemes, there was a much clearer division between the Glastir WC and WM schemes and the farm-based Glastir Entry and Advanced scheme as a whole. Therefore the opinions expressed by the Coed Cymru officers are largely based on the WC and WM sections of Glastir.

It is interesting to note that there was a high degree of similarity between the opinions expressed by the Coed Cymru officers and those from the farming community. In general, it seems that previous experiences, both good and bad, either with the All-Wales elements of Glastir or with previous woodland schemes, colour the attitudes towards the current scheme. For example, farmers who are already involved in Glastir and have had a negative experience appeared reticent about entering another Glastir scheme. Likewise, both farmers and Local Authorities compare Glastir to previous schemes and there is an expectation that Glastir should have built on previous woodland schemes (for example Better Woodland Wales) and a disappointment as this is perceived as not having happened; this was particularly acutely felt within the Local Authorities.

"To be honest most probably we hadn't really looked at the Glastir Woodland too significantly because the other requirements of Glastir processes have said you know I don't want to really go for that and it's the documentation exercise more than anything of Glastir. And we have enough paperwork as it is." **R6, Abergavenny**

"We were in the ESA which was really good scheme and you had an individual person came out, walked around the farm with you, decided what you'd do and helped you with all the paperwork when it had to go through. And it worked brilliantly and we didn't go into the last lot, Tir Gofal and then we've gone into this one but its nothing like as good as the ESA. Yes, I think the ESA was more, it was more simple wasn't it?" **R6, Bangor**

"Under Woodland Improvement Grant there was a degree of flexibility like if you know you couldn't do it this year for whatever reason you could phone them up and say look we can't do it because it was too wet or too whatever. It was a case of alright we'll just put it down for next year then and there just doesn't seem to be the opportunity to do that with Glastir." **LA1**

Figure 3.1: Quotes reflecting attitudes towards the Glastir Woodland schemes in comparison to previous schemes

3.2 Glastir Woodland Management and Creation

Concern about the finer details of the Glastir WC and WM schemes were most often expressed by Local Authorities, for example the minimum area requirement, species mix and thinning rates, reflecting a greater scheme-specific knowledge of the Coed Cymru officers. In contrast, members of the farming community talked much more generally about Glastir, and openly admitted to being strategic in terms of what land they enrolled into the scheme and which options under Glastir they would participate in. Oftentimes this reflects works that the farmers had been planning to undertake anyway, and entry into Glastir was merely a method of achieving the end result with a smaller financial burden. In both cases, dissatisfaction and unhappiness, either with scheme-specific details or more generally with the perceived complexity and bureaucracy associated with the scheme expressed by most participants undermines the overall objectives of Glastir WC and WM. This corroborates much previous research in which landowners perceptions of woodland grant schemes are described s complex and bureaucratic (Urquhart 2006; Church and Ravenscroft 2008; Cunningham 2009; Urquhart et al. 2009). Despite this, the Better Woodlands Wales (BWW) scheme examined by Wavehill Consulting (2009) was deemed to be straightforward, which perhaps explains the disappointment felt by LAs that Glastir Woodland schemes had not built on the success of BWW.

"I find that I looked through all the Glastir paperwork this morning and I thought my goodness! [Laughs] I, we were actually offered a contract and we'd already done all the work we'd suggested that we might have grants on and at the end of the day we didn't bother to fill it in, the contract was so demanding!" **R3, Wrexham**

"We're now in Glastir and will be in Glastir Advanced but we're being really cautious about which bits of the land we tie down . . . We're still trying to do it but we have been much more strategic about which bits we'll say we will commit to Glastir." **R5, Bangor**

"Well I mean if we take the reclamation woodlands you could put the reclamation woodland sites in for a thinning operation whereas you couldn't do that under Glastir because you just simply can't the 27 cubic metres volume out of there per hectare. Where if you went into Better Woodlands for Wales you could, you could thin any volume you wanted but you were paid on you know on how much volume." **LA2**

"Each grant scheme has got progressively more complex in its application process and I would say each grant scheme, because of that, has been more costly and less effective." **LA3**

Figure 3.2: Quotes reflecting attitudes towards the current Glastir Woodland schemes

3.3 Productivity versus woodland creation

There is a well-documented conflict between agricultural productivity and woodland creation (Watkins et al. 1996) where it has been shown that farmers have a tendency to see the creation of woodland on agriculturally valuable land as wrong and even immoral. In this research, the reaction to the arable scene in the photograph exercise did indicate an aesthetic preference for an arable landscape, a finding similar to that of Burton and Wilson (2000). However, the qualitative nature of the methodology used allowed an in-depth exploration of this, revealing nuances that do not quite align with the established consensus held in the literature. Whilst all but one farmer would not seriously consider planting woodland on productive land, the vast majority agreed that there were small pockets of land that could be given over to woodland creation. This contradicts previous studies that indicate a much stronger aversion to planting woodland on any farmland (Watkins et al. 1996; Burgess et al. 1998).

"I feel that a good farmer being brought up in the generation before me farming was always taught that we had to feed the nation or nowadays with the world being so small, feed the world and so that is where some moral dilemmas arise with the Glastir work." **R5, Abergavenny**

"Because like that's you've got your corridors, you've got your livestock, you've got your hedges for shelter and the hedges are growing they're tidy you know decent hedges." **R3, Abergavenny**

R1: Yeah that looks attractive, it looks well kept, it looks farmable you know practical erm...
R4: You've got trees dotted around haven't you so yeah
R3: And there are like wildlife corridors in the long hedges
Wrexham

"I think most farmers have small pockets don't we that could be converted into woodlands, I think we've all got a little bit somewhere." **R4, Wrexham**

Figure 3.3: Quotes reflecting attitudes towards the current the agricultural landscape image

Many participants were of the opinion that there is a range of more appropriate places for woodland creation than productive land, for example road verges. Osmond and Upton (2012) found that in order to meet target of new woodland creation by 2030, areas of marginal land will need to be planted; however, conservation agencies often oppose planting applications because of the ecological importance of the existing habitats (Osmond and Upton 2012).

"There's always ground at the sides of these roads and they're paying the councils just to try and cut the grass off it and you think you know there's a degree of ground there that could be planted." **R5, Wrexham**

Figure 3.4: Quote reflecting attitudes towards appropriate woodland location

Furthermore, despite the reference to a desire for tidy farms expressed by the famers in this research, which corroborates the findings of Silcock and Manley (2008), this preference for tidiness did not extend to the woodland; moreover, many of the farmers expressed an appreciation for untidy woodland in terms of its importance for biodiversity. Any reticence about creating woodlands strongly reflects the concerns about and perceived barriers of the Glastir scheme itself as opposed to an aversion to woodlands *per se*. Examples of this include concerns about the penalties and auditing or the inflexibility and lack of adaptability of Glastir such that it is perceived as being more hassle than it's worth. This mode of thinking is also apparent in the interviews with Local Authorities; whilst woodland creation on Local Authority owned land could be hampered by limited suitable space, woodland management is an on-going work stream. Again, reticence about engaging with the Glastir WM is more focussed on the perceived drawbacks, particularly the increased administrative burden and lack of flexibility of the scheme, and not a lack of impetus to manage Local Authority owned woodlands.

" . . there's not enough flexibility for individual farmers to keep control of the situation under different weather conditions and different stock conditions and so on and that's a major problem which is why with our Glastir we thought long and hard about what we wanted to do . . we were very careful about what we put in and what we didn't" **R5, Bangor**

"I think that the word that sums it all up is balance because areas like that there's nothing at all wrong with them, especially if its on the poorer ground, its being wonderful for the environment, its non-productive land, the timber doesn't even look any good for firewood, its just a balance which life has got to be all about." **R5, Abergavenny**

Figure 3.5: Quotes reflecting a desire for Glastir woodland schemes to be flexible and in balance with other farming priorities.

3.4 Relationship between farming culture and Glastir Woodland schemes

It was important to first understand the perceptions behind what makes a good and bad farmer before trying to unpack how the Glastir woodland schemes fit into the farming lifestyle, in line with the need to "create a business case for woodland creation that works with farming culture" (Wynne-Jones 2013a). The attributes of both good and bad farmers discussed by our farming participants allowed contextualisation of the attitudes towards both woodland and the Glastir schemes. In brief, 'good' farmers were considered as those who achieved a balance between productivity and caring for the environment. Both of these were seen a key contributions that the farming communities makes to society, encompassing the responsibility for land stewardship and providing food nationally and internationally. It is important to note the productivity does not necessarily equate to profitability; whilst it was acknowledged that farming is a business and profits are needed in order move forward, the importance of farming as a way of life and that the profit margins are not expected to be large was also expressed.

"So it is getting that balance and no matter how much your heart says I want to go this way, I want to protect my hay meadow which has got wonderful flowers on it, but we also have to grow grass on it and its trying to find the balance of sunflowers and lots of grass so we can feed the sheep in the winter and not have to buy in fodder." **R5, Bangor**

"Just to roll on from that of course the best thing for the environment and for the countryside is profitable farming because if farmers are making money they will repair the walls, put up new gates, look after the countryside, if we've got no brass in our pockets we're not going to be doing that. So profitable agriculture is probably the best thing, I feel, for the environment and for the countryside in general, it is vital that agriculture makes money." **R5, Abergavenny**

"You know if you take the schemes out you know to sort of put your most productive land into sort of schemes that are not going to help you make your profit is harder and harder." **R3, Abergavenny**

"And I think for me a bad farmer is somebody who doesn't care for the environment because there's that notion of sustainability that if you take no notice of what you're throwing on the fields or you know chopping down hedges and trees and all the rest of it then ultimately you're not going to be successful. I suppose you might still be successful as commercially as a farmer but in terms of the long-term view of food production you're not, you're not going to make it. **R5, Bangor**

"Some of the trouble is what are you talking a 'profitable farmer' because we're profitable because we get Single Farm Payments, there's not many farmers who actually can make a living without the Single Farm Payment, or without subsidies." **R1, Abergavenny**

Figure 3.6: Quotes reflecting the complexity of attitudes relating to farming and the environment

An interesting point raised in the Abergavenny FG was that profit-making farms are more likely to have the spare capital to invest in the environment. This connects with the perception that most of the farming community expressed, about farming being a lifestyle choice and how farming relies upon a healthy environment and embodies a duty of care towards the environment. Furthermore, the need to rely on subsidies, such as the Single Farm Payment (SFP) or indeed Glastir schemes in order to show a profit at the end of the day was also explicitly mentioned, adding weight to the idea that farming is accepted as being more of a lifestyle choice that a profit making industry.

Adaptability and resilience were also important attributes of good farmers, driven by the perception that agriculture is subject to external influences which creates uncertainty, for example climatic and political drivers. The need to be able to adapt and to be resilient in the face of changing political priorities, uncertainty over product prices and little control of the weather was seen as very important to the success of anyone within the agricultural sector. In general, most participants felt that the Glastir scheme was inflexible and overly prescriptive, an opinion also voiced strongly by the Local Authorities. In tandem, strong concerns were voiced over the penalties for not adhering to the works timetable agreed (by both farmers and Local Authorities), particularly if work was not able to be carried out due to unforeseen circumstances beyond the landowners control, for example an extremely wet winter preventing access to woodlands. Moreover, the Glastir scheme was viewed as having no mechanism whereby changes to the scheduled programme of works could be adapted following such events. The Coed Cymru officers made comparisons to the Better Woodland Wales scheme, which they believed to have had more flexibility than Glastir WM or WC, due to ability to adapt the planned operation to take account of circumstance beyond their control (i.e. weather).

"Yeah I think you have to be resilient because not only is the Government changing the rules every now and then but also we have no control over the weather and so you have to be prepared to adjust and make the best of whatever is thrown at you in terms of the weather and disease" **R5, Bangor**

"I personally haven't gone into Glastir, will not go into Glastir. Didn't go into Tir Gofal basically because they don't listen to you…when you tell them how a field, every field grows differently but they just…broad brush 'no you can't do that, you can't do that' and it doesn't work. **R3, Bangor**

"You get form after form that's like this thick within its booklet and it gets to the stage where you just think pfft [sic] you know its piles of them and then you're thinking if I get something wrong are they going to come down like a tonne of bricks. And half the time you don't even know if you've done something wrong until somebody comes and tells you. And you, you know, you end up thinking god I better not join this scheme in case I make a mistake and then I'm going to have all kinds of hassle and bother." **R2, Bangor**

"The only thing, the only thing that I'd be wary of with the Glastir Woodland Management is not to commit the Council to too much work under the scheme because of the way the scheme rules if you default on an operation then you will get fined." **LA4**

Figure 3.7: Quotes reflecting the participants' fear surrounding the auditing component of Glastir

3.5 General attitudes towards woodland

Attitudes towards woodland are intertwined with the key attributes of an effective famer; whilst the positive contributions woodland can make to land management in terms of flood management, biodiversity and shelter for livestock and crops are accepted, the idea taking productive land to plant trees on is the antithesis of the primary reason for farming i.e. to produce food. All but one farmer that participated in this research was opposed to taking productive land and converting into woodland. Moreover, there was an expectation expressed that should this happen, that farming would become more intensive in order to compensate for the loss of agricultural land. The single farmer who had converted some of his grazing pastures into woodland did so out of a belief that agriculture has become too intensive and was detrimentally impacting the environment. As such a key concern for farmers was the environmental impact of intensive farming practices. However, it was also accepted that there is a balance between profitability and caring for the environment and that farming is a business that needs to be profitable in order to survive. Concern was also expressed about whether agriculture in the Wales is economically viable if subsidies or payments for ecosystem services (i.e. Glastir) were not accounted for.

"Well if I may say I think this over-intensification of farming I mean up a level from we do. It's dreadful factory farming, these chickens in hundreds of thousands and if you're going back to profitability I think all we need to do is make a living." **R3, Newtown**

"and they could have had quarter of an acre to go with it [the other land planted for woodland] but leave me farm more intensive farming in another acre somewhere else you see." **R2 Newtown**

R7: We had, we had some very steep hillside when we went into the farm and it was completely covered in bracken and we did take out one of those schemes, it was a Forestry scheme and we planted it with trees and we found that the amount of bird life and other life that we've now got on the farm has tripled, quadrupled.
Kate: And is that something that you see as a positive feature now?
R7: Yes. **Abergavenny**

I have planted 14 odd hectares into woodland in a Glastir scheme and yeah the moral decision to plant on land that could produce food was quite a difficult one. **R5, Abergavenny**

"that's the key responsibility its not only providing our yearly income is it not but to achieve that you've got to look after the land, you keep it in good condition and these interests which you must have in the environment you must be supportive of it." **R1, Newtown**

Figure 3.8: Quotes reflecting environmental stewardship of farming and positive attitudes towards woodland creation

As previously mentioned, many participants acknowledge that there are small pockets of land on most farms that could be planted with trees, and in principle would be happy to do so, and felt confident in having the skills or knowledge to undertake such work. However, woodland creation or management would not be undertaken just for economic reasons. The length of time to maturity and the amount of work necessary during the first 10 years meant that participants believed that aside from providing wood fuel for personal use in the home, there would be little possibility for making profit from woodland; in combination there was little knowledge about whether one would be allowed to harvest wood from woodland that had been planted under the Glastir scheme. That being said, many participants expressed an affinity for woodland and several had already planted trees on their land, outside of the Glastir schemes. The delicate balance between farming the environment mentioned previously was brought up again when participants were comparing the four images of woodland; the image of a field bounded by woodland was described as being a good compromise, further highlighting the almost unanimous opinion that woodland and farming are not mutually exclusive but that farm woodlands need to be sympathetic to the food production focus of farms.

"Well we got one 18 acres, it's called the Large Wood which is mostly oak trees and they're almost like telephone poles and they want to be thinned but the cost of thinning is going to be way more than what you know just merely the price of firewood really, we can't a home to sell it." **R2, Newtown**

R4: Yeah that's what we think, best of both worlds really. You've got the wood and you've got the farmland as well.
R3: Well now then tree planting is, serious trees hardwood and so on is a long term matter. I agree the financial incentives are nowhere near large enough. I don't think we're planting for profit for use, we might be for our grandchildren . . .
R2: I have no children or grandchildren and we've planted a lot of hardwood, it is for the future, its sustainability. **Wrexham**

Figure 3.9: Quotes reflecting the financial incentives of Glastir woodland schemes.

3.6 The Glastir Process

General criticisms of the Glastir scheme itself included the relationship between the staff administering the scheme, and the administrative requirements of entry into Glastir. For those participants who had received an on-site visit, the opinions were generally positive about the member of staff who visited. However, for those that had no face-to-face contact, opinions were jaded by perceived complexity and administrative burden in placed, both on Local Authorities and farmers. The need to register all woodland within the LA was seen as a burden by the LA interviewees, due to organisational set-up within the Local Authority. More than one department have responsibility for woodland in Local Authorities, and this alongside the numerous small pockets of woodland on LA land mean that it can place an unwieldy administrative burden on LA's to document and register each patch of woodland.

The planting eligibility maps were a source of frustration across both the farming community and the LAs. This has been previously highlighted by Wynne-Jones (2013a), who found that the these maps were both a direct disincentive and an indirect barrier by attempting to encourage planting in lowland fertile regions and consequently increasing the conflict between food production and woodland creation. Planting maps continue to be perceived as inaccurate and a disincentive to express an interest in Glastir WM and WC, to both LA's and farmers. Additionally, inaccuracies on the individual farm maps were common; despite this, even when farmers corrected the maps and sent them back to Glastir, the corrections were not updated centrally and incorrect maps continued to be send out.

"Erm well yeah when you've got something as complex as that then yeah it does add an additional sort of burden on the Council to start actually looking at what they've got regards woodlands because to be honest I don't think they know themselves [laughs]" **LA1**

"each time I've had my IACS maps which are sent to you each year showing your boundaries and somebody somewhere has taken these boundaries from I presume a satellite photo. There was a small error in that a pond that was part of my field was marked as belonging to my neighbour as was a hundred metres of ditch. Now it doesn't really matter but I thought I'd better write to them and say 'look this is my ditch not his ditch' and 'that's my pond not his pond' because you know probably somebody somewhere would then say 'those aren't yours because you never said anything about it'. So I wrote I think for four years running, never got a response and then I got a response this year which was the one year I hadn't bothered writing because I'd given up" **R2, Bangor**

"The woodland creation was done on the basis of, in principle which was a good idea, but it was to plant on land where you're not going to damage an existing habitat so it was done on the All Wales Map Scheme based on Phase 1 survey data which was really quite out of date." **LA3**

Figure 3.10: Quotes reflecting the participants' perceptions of the Glastir process.

There was also the perception that the Glastir scheme was constantly changing and a feeling that the scheme was rolled out too early; moreover, experiences of the Glastir administration left some participants feeling as if there were internal conflicting opinions within Welsh Government. This finding emphasises the conclusions drawn by Wynne Jones (2013a) that contrary to accepted practises, the Glastir scheme should not reduce staff numbers and face-to-face contact with farmers and that a move towards more automated approach in not appropriate in this context. Above all, a degree of continuity was needed to allow both LA's and farmers to feel confident dealing with the schemes and to develop a sense of trust in the scheme, perceived as lacking at the current time. These comments refer to Glastir in general, but such attitudes represented a significant barrier to the uptake of Glastir WM and WC and are thus important to highlight.

"There is no communication between the Glastir Woodland Management and it doesn't come, it goes to the client and the client is who doesn't really understand woodland management but wants to do it and while I've been there you know he should be liaising with myself but doesn't do it, he just goes ahead and writes the plan. Now then the plans go away then the plans then go away and that Glastir Woodland Advisor doesn't see that plan once it's gone in-house into Welsh Government because it's another team that's building it all up. There's another mapping team in Aberystwyth who produces the maps and invariably you've got no communication, information comes out wrong, the maps are wrong and they're expected to sign you know when eventually the contracts do come through I don't know any client yet who has had a contract on time ready to sign." **LA5**

"Every other department has got a different agenda and they don't work towards the same goal, or lots of them." **R3, Bangor**

"We need a continuity of a scheme that can actually deliver you know on a, on a basis well a five review is great and it could be you know continue to be that. Because of the demise of BWW and they're starting again with Glastir I'm hoping now that Glastir can offer this kind of continuity." **LA3**

Figure 3.11: Quotes reflecting the participants' perceptions of the Glastir administration and scheme continuity

The complexity of the Glastir WC and WM schemes begins on application, when new entrants have to choose from a long list of possible options that they might want to undertake. Often, Woodland Creation Officers are met with farmers who want to undertake works that are not suitable for their land or impractical or not allowed as a result of the tree planting maps. As a result, farmers often become frustrated and less amenable to going into Glastir WC.

"I mean if you're talking about the Glastir from the point of view of the landowners well with the Council in mind from the point of view of me as a Woodland Advisor erm…you know there are certain issues with the scheme but there are with all the schemes [laughs]. Complexity, issues, the I mean you do get this its almost like a Christmas list when you turn up at a landowners who have seen the matrix of operations that they could be eligible for and what we tend to find is you turn up and they've gone through this going like we want that that that that [laughs]. You know, hang on hang on you know and you're having to sort of reign them in a bit and say no look you've only got these layers on your land and then its oh oh I don't think we're interested now if we can't get that you know its sort of disappointing really so from their point of view." **LA1**

Figure 3.12: Quote reflecting the participants' perceptions of the complexity of the Glastir

3.7 Payment Rates

Opinions about the payment rates under Glastir WC were divided; one farmer felt that the payment they receive made is economically viable for him to convert pastureland into woodland. However, many other participants felt that the payments were not in-line with the true cost of operations. The LA interviews revealed that woodland management rates, particularly for thinning, were in some cases insufficient to overcome the perceived administrative burden of entering Glastir Woodland Management. In many cases the LAs were not looking to increase their woodland holding by creating new woodland, predominately because they did not have the space (space constraints on grant uptake were also found in (Watkins 1984) or in these time if fiscal austerity, woodland creation has to compete with other priority areas for LA finances.

"They gave us loads of money for thinning the forest that's going to more or less pay for itself anyway and there's about the same amount of money for putting in the track that cost about six times that." **R6, Bangor**

"Yes I think for something like thinning or habitat restoration it's probably not actually important because we're not getting that much payment for it. For other sorts of work it really depends on the payments we're getting really I mean work like sort of fencing like access if we can get it its going to be crucial to doing the work." **LA6**

"You know when they say the 50%, there's a grant of 50% it invariably turns out to be more like 30%." **LA5**

"Because there's money going out with no you know they can maintain and upgrade footpaths etcetera at their own cost if needs be, you know where public access but where if there's no money to do the work there's no money to do the work and with regard to thinning etcetera and creating new footpaths" **LA7**

Figure 3.13: Quote reflecting the participants' perceptions of the Glastir payment rates for

A theme present across each focus group was the role of the public, both as a contributor through taxation to farming subsidies and as a driver of landscape evolution. Glastir as a novel agri-environment scheme has moved towards a payment for ecosystem services approach, with Welsh Government as the customer and the farmer as the supplier (Wynne-Jones 2013b). However it was unclear if this concept was one that the farming community engaged because Glastir and Single Farm Payments were discussed simultaneously in the discussions. The concept that woodlands would help to offset the carbon emission from agriculture was accepted as a powerful driver of woodland planting targets, but there was a concern about whether this would impact consumer choices. There was a perception that the public has a lack of understanding about the true cost, both financial and in terms of land management, of food production. There was a sense of frustration and a feeling of under appreciation for the care and management for the countryside that farmers undertake, which also manifested itself in a frustration about the fact that Glastir payments are only made on work to be done, rather than compensating work that has been already been undertaken.

"there's a great number of people who have another job and a lot of people are subsiding farming" **R1, Abergavenny**

"our food prices are just way too low, always have been, possibly always will be and until we can relate to the consumers and say 'you think its expensive but its not' because they don't realise how much money is going out in the Single Farm Payment, its almost like there a middle man giving us money to keep the consumers quiet and once we tell the consumers that they're actually not paying, very little for their food and we actually [?] payments through the back pockets through the Single Farm Payment then we might then work out whether we are profitable or now and whether people want us to be profitable or they want us to be just farm keepers really." **R1, Abergavenny**

"If you've got a nice little woodland that's well managed and well fenced in the last five years and haven't had grants on it otherwise we will pay you for that effort instead of this applying to do this and do that but lets look at people's conservation and say yes that, it would be better to reward them for what they've done." **R3, Wrexham**

Figure 3.14: Quotes highlighting the role of the public in agricultural profitability and the desire for acknowledgment of the environmental stewardship role most farmers undertake.

4.0 Conclusions

This research has highlighted the complicated nature of landowners' (farmers and Local Authorities) relationships with Glastir and how this relates to attitudes towards woodland creation and management. On the one hand, there appears to be little evidence that farmers do not want woodland on their land or that Local Authorities are not actively managing their woodland holdings. Moreover, there were positive reactions to landscape images that included woodland from the farming community. Yet on the other hand, there are significant barriers to be overcome if either publically or privately owned land is to contribute towards the Welsh Government's 100,000 ha target. A balanced, straightforward and flexible scheme needs to be created that allows woodland creation and management to be carried out in keeping with the needs of both farmers and LAs.

4.1 Compatibility of Glastir Woodland elements and farming culture

The provision for woodland creation and management within Glastir do not appear to be compatible with key attribute of farming culture, as identified by the farming community who participated in this research. The perceived lack of flexibility in the scheme means that several participants explicitly stated that they would plant woodland, but not under Glastir. The prescriptive nature of the Glastir scheme (In terms of size and widths) is also a barrier because it prevents many landowners from being allowed to create woodland on parts of their farms which best suit their needs, i.e. small disparate patches which are unused, irrespective of farm size. It is important to recognise that farming is a business and needs to be profitable; moreover, farming as a culture with strong values and attitudes means that that a focus on adapting Glastir to suit the farmers is going to have a greater chance of success, both in the short and long term, rather than trying to change farming values and attitudes. The prescriptive nature of Glastir also prevents Local Authorities for engaging with the scheme fully, and represents missed opportunities for funding woodland management above the minimum required from LA's.

4.2 Streamlined Glastir Process

Many of the general comments about Glastir related to the process of entering the scheme; although this does not directly impact Glastir Woodland Creation or Management uptake, it is nevertheless a barrier to entering into any part of the scheme, which has an indirect consequence of reducing participant numbers in the woodland schemes. Scheme complexity was detrimental to both farmers and Local Authorities and was cited by some participants as a reason not to go in Glastir schemes. A more streamline process which still uses face-to-face consultations to help landowners decide on the most appropriate operations for their land management goals would help to alleviate frustration felt as a result of excessive paperwork and time taken to apply for the scheme. Clearly outlined simple objectives, alongside an in-built evaluation process to taka the place of the current auditing element, would allow scheme entrants to feel more at ease with what they should and should not be doing, and to try to remove the fear factor when it comes to auditing and penalties. The evaluation process would also allow increased flexibility in case of situations where work has not been possible due to weather conditions or other unforeseen circumstances.

4.3 Payment Rates

The payment rates under Glastir were perceived to be incompatible with the true cost of the work involve in either creating or managing woodlands. The Glastir scheme seeks to pay for ecosystems services that it believes would not be created or maintained otherwise; perceptions were that payment rates were not sufficient to overcome the other barriers to entering Glasitr (for example the perceived inflexibility of the scheme) and encourage participation across the board. Creating and managing woodland take time away from other tasks, particularly in the case of farmers, and represents a financial pressure for LA's in challenging economic times. Greater scheme uptake could be encouraged if payment rates included costing for labour (aside from the landowner's time) as many forestry operations require specialist equipment and/or personnel.

4.4 Final Reflections

Overall, these findings demonstrate that the gulf between farming and forestry appears not to be as significant in Wales as has been found elsewhere in the UK, suggesting that the that the 100,000 ha target is not unachievable. Indeed, Welsh farmers exhibit positive attitudes towards woodland that are not based on economics; many have planted or will be planting trees on their land and agree with the major tenets of Glastir. The major barriers to entry into the Glastir woodland scheme (both WC and WM) exist within the scheme itself, and do not reflect attitudes towards woodland. Remedial action to the design and attributes of the scheme based on these findings may yield a more customer-focused scheme and consequently higher rates of scheme uptake.

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Appendix A: Literature Review

A-1 General attitudes towards forestry

No real tradition of farm forestry exists in in the UK, unlike other European countries (Burgess et al. 1998) and so there appears to be a tendency for farmers to see forestry as very distinct from agriculture. Moreover, some attitudes imply that using productive agricultural land for forestry is almost morally wrong (Watkins et al. 1996), as if because of productivity of the land is should only be used for agriculture and is a waste of such land (Bell 1999). Work by Walker-Springett (2014) shows that both farmers and those connected to rural locations, can have a utilitarian or anthropocentric attitude towards nature. Agriculture is perceived favourably because it produced a tangible output (i.e. food and money); the land is considered wasted if food production is limited as a result of a land use change where the services are less tangible such as flood alleviation or biodiversity enhancement. In a study in Scotland, concerns about food security were given as a reason for not planting trees on productive agricultural land (Secker Walker 2009).

Unlike crops or livestock, woodland creation takes a long time to mature and cannot be easily converted to other uses, unlike crop production which is much more reactive to market forces (Burton and Wilson 2000; Silcock and Manley 2008). Time scales are much longer and acceptance of grants means that the landowner is tied into to the scheme for a long period of time (Burton and Wilson 2000). The need for felling licences to return the land to agricultural use at the end of the scheme further compounds the belief that conversion to woodland is an irreversible decision (Bell 1999; Cunningham 2009).

The implication for agri-environmental schemes (e.g. Glastir) of this type of attitude is that those who take up grants use the least productive land. They might not be open to planting forest on the most appropriate or beneficial sites and therefore are unlikely to see benefits such as reduced runoff and erosion, which have been demonstrated by the farmers at Pont Bren (The Woodland Trust. n.d.). If farmers are not seeing the benefits of woodland creation, then there is no incentive for them to recommend the scheme to other farmers.

Attitudes towards agriculture stem predominantly from within the farming community; there is a social status achieved through good farming and the favourable aesthetics of crop management compared with the untidy appearance of woodlands (Bell 1999; Burton and Wilson 2000). Farming is evolving into the production of goods *and* services, which might subtly change attitudes toward forestry and its uses and aesthetic value. Burton and Wilson (2000) point out that to change farmers into farmer-foresters will require a change in the perception of what a good farmer actually means. The authors include the term 'leisure provider' in their farmer-forester description; this insinuates that by creating forest, farmers would then automatically become leisure providers, leading to issues such as accessibility and privacy, which have been given as reasons for landowners not to plant woodland. Farmers themselves state that they have less of a knowledge base concerning woodland (Bell 1999) thereby reinforcing the idea that farming does not include forestry. Secker and Walker (2009) suggest that this knowledge gap is a disincentive to attempt forestry management. However, in a previous study Betts and Ellis (2000) found that three-quarters of the farmers surveyed wanted more information about woodland management, suggesting that farmers have an interest in forestry management.

A-2 Socio-demographic influence on attitudes

Gasson & Hill (1999) found that younger farmers were more likely to plant woodland than older farmers. A study in the 1980s revealed that some farmers believed that the conversion of agricultural land to woodland was a long-term option, which might in part explain the reticence of older farmer to become involved in woodland creation schemes. Age is also linked to the prospective of financial returns from the woodland creation; Watkins et al. (1996) found participants felt that older farmers who planted trees were less likely to see a return on their investment. Alternatively, Silcock and Manley (2008) postulated that older famers might prefer the less labour intensive aspect of forest management, where forestry contractors can be used. In keeping with difference in attitude as a result of age, a line of succession for the farm leads to more active management of land in general, which can include woodland planting and management (Gasson and Hill 1990). If there is a clear succession then perhaps there will be a greater tendency for woodland creation, as the 'planter' would know that whilst s/he might not see the profits, his/her children would.

Public access to privately owned woodlands is seen as a barrier to woodland creation (Bishop 1992). Despite this, a study shows that only a few farmers were reluctant to allow access to their woodland (Church et al., 2005) . Whilst another study found that two thirds of respondents whose land includes pubic right of way have had no problems associated with the public access (Church and Ravenscroft 2008). Church and Ravenscroft (2008) also found that famers with woodland and allowed access, were happy to increase access provision. Sime et al. (1993) found that there was a hierarchy of groups that farmers were happy (and less happy to allow access to) for example bird watcher and local people were in the 'good' group, town dwellers were tolerated and mountain bikers and campers were discouraged.

In interview study involving Welsh Farmers by Wavehill Consulting (2009) found that the majority of participants actively use their woodland. In general a higher proportion of those who receive a grant use their woodlands for recreational purposes, as well as timber production and the enhancement of habitats for wildlife, than those who were not involved in a grant scheme (Wavehill Consulting 2009). Furthermore, a high proportion of those who receive a grant actively manage their woodland (i.e. thinning), although landowner perceptions of appropriate management is often not congruent with policy makers ideas of correct woodland management (Lawrence and Dandy 2014). Woodland is also commonly planted to provide or encourage: shelter for livestock (Burgess et al. 1998; Blackstock 2000; Wavehill Consulting 2009). Moreover, wildlife/conservation, sporting/recreation and shelter/boundaries are consistently the top aims of woodland owners who had received grants.

A-3 Efficacy of Grants

The provision of grants for woodland creation and management does not have a clear-cut effect on the quantity of woodlands created or managed. Watkins (1984) found that just under half of owners who participated in their study would have planted woodlands irrespective of grant availability. However, Sharpe et al. (2001) found that most woodland owners stated that more grants would encourage them to bring their woodland under management . But these studies focus on woodland owners who may or may not be farmers. Conflicting attitudes from participants who were and were not involved in commercial forestry were highlighted by Church and Ravenscroft (2008) who found that the majority of private owners of woodland not involved in commercial forestry felt that the grants were not relevant to their decision to plant woodlands as the woodland was not planted for financial return. However, the same study found that 60% participants who were involved in commercial forestry did state that grant were important in their decision-making. Crabtree and Appleton (1998) found that scheme payments under-compensate for direct and indirect costs of woodland creation, but in this case woodland creation was based on the conversion of high quality arable land to woodland.

Cunningham (2009) indicates that barriers to grant uptake include bureaucracy, and overly complex application process. Dandy (2009) indicates that the grants are perceived as not dependable and likely to decrease in the future. However, this would be partially nullified by the current practise of guaranteeing a fixed price for a period of time; but farmers recognise that this is still subject to the funding priorities of the EU. Conversely, a study in Wales found that 90% 0f those in receipt of Forestry Commission grants for woodland ranked the scheme as good or very good (Wavehill Consulting 2009); the most common reason for this was the financial incentives in place. Of those that had not received a grant, lack of knowledge was a key factor in determining that they not apply for a grant (Wavehill Consulting 2009). Whilst lack of knowledge about the available grants has been shown to be a barrier to uptake (Ward and

Manley 2002; Wavehill Consulting 2009), Crabtree et al. (1998) show that a lack of knowledge was strongly associated with other predictors of non-participation and concludes that is impossible to cite knowledge as the sole or main reason behind a lack of grant uptake.

Economic valuation exercises with landowners indicates that many woodland owners are not aware of the economic value of their woodland; this links with evidence from Sharpe et al .(2001) about the lack of economic incentive to manage woodlands and the perception that productive agricultural land would be wasted as forestry (Watkins et al. 1996). It is suggested that a lack of awareness of the potential revenue from woodland is a barrier to grant uptake (Lawrence et al. 2010). Revenue obtained directly through woodland (for example firewood etc.) are often not the main motivator for woodland creation (Blackstock 2000; Church and Ravenscroft 2008). Relatively few farmers use their woodland for commercial timber production (Church and Ravenscroft 2008) but this could be due to a lack of belief that woodland can offer large-scale economic returns (Burton and Wilson 2000). Conversely, Shape et al. (2001) found that 87% of woodland owners would be prepared to manage their woodland if this was a no cost to themselves (i.e. they broke even). In fact, woodlands are often unmanaged because it is not economically viable to do so (Sharpe et al. 2001). Secker Walker (2009) found that farmers do not perceive short rotation coppicing (SRC) (not eligible for Glastir payments) as giving a greater financial return than traditional agriculture and that the wood-fuel market is uncertain. The wood-fuel sector is seen as lacking a regional market structure, being complex, and having a lower long-term market viability (Dandy 2009). A report for Forestry Commission Scotland highlights the reliance of farmers in Scotland on unpaid family labour, which tends to artificially inflate farm profitability. Once this is factored out, forestry becomes more completive in comparison to more traditional agriculture.

Lack of suitable land is also a barrier to grant uptake, Watkins et al. (1984) found that the most frequent reasons given for not planting trees was not having suitable land to plant; under the Glastir scheme the smallest amount of land eligible for payment is 0.25 ha. The average size of the woodland in a grant scheme was 22 hectares compared with 5 hectares on average for woodland not in a grant scheme (Wavehill Consulting 2009). This links to general attitudes towards forestry, where spare, poor quality or less useful land is converted to forestry; smaller farms are less likely to have pockets of un-used land. The focus on the minimum entry size required by Glastir further restricts entry for those farmers who only have small pockets of land (Osmond and Upton 2012).

This also links with the previously discussed attitudes towards forestry; suitable land often means land that is not good enough for crop planting or livestock grazing (Bell 1999).

Additionally, an acceptance of grants is can be perceived as involving a loss of control over the land involved in the grant scheme (Sime et al. 1993; Urquhart 2006; Urquhart et al. 2009). Private woodland owners have been shown to have a strong sense of attachment to their woodland (Sime et al. 1993; Urquhart 2006) and to be against any loss of control, related to both public access and management regulations. Loss of control could be inadvertent as a consequence of environmental legislation and protection stemming from the woodland creation (Watkins et al. 1996).

Socio-economic evaluation of Glastir Efficiency Scheme

Helen Taft, Paul Cross & Dave Chadwick

afpc5c@bangor.ac.uk; Paul.Cross@bangor.ac.uk; d.chadwick@bangor.ac.uk>

School of Environment, Natural Resources and Geography, Bangor University

On behalf of the Glastir Monitoring and Evaluation Project

January 2015

JMMARY

Executive Summary

This report focuses on the Glastir Efficiency Scheme (GES), previously known as the Agricultural Carbon Reduction and Efficiency Scheme (ACRES). The GES provides grants to farmers and land managers to improve farm management, particularly to improve Slurry and Manure Efficiency (SME), Energy Efficiency (EE) and Water Efficiency measures (WE). Through these grants, GES aims to improve resource use efficiency and reduce the environmental effects of the agriculture sector, and in particular, the dairy sector. This study surveyed recipients of GES grants and evaluated the socio-economic impact of the scheme at a regional scale. We report herein on the following criteria:

- Grant allocation – the current status of approved grants, and grants in progress;
- Economic outputs and efficiency of farms;
- Labour – how employment has been impacted;
- The wider economy – farm expenditure, what money is being spent on imports and tax.

Of the 157 Glastir Efficiency Scheme participants in June 2014, 120 surveys were completed for analysis and discussion in this report. A total of 383 GES grants were approved and of these, 327 were awarded for SME, 39 for EE and 17 for WE measures.

Current status of GES grants

Of the 120 completed surveys, 59% of respondents farmed on LFA cattle and sheep farms, a further 30% on dairy farms, 7% of farms were described as 'other' consisting of various main farm types and 4% of farms did not specify. A total of 305 grants were approved for farms in the survey. EE grants accounted for 9.2% of total approved grants, 7.9% were assigned to dairy farms, 1.3% to 'other' farms and none to LFA cattle and sheep. Grants awarded to LFA cattle and sheep farms were nearly all for SME (174 of the 179 approved grants).

The total monetary value of the paid grants amounted to £1,006,490. No WE grants were in progress by July 2014. SME grants accounted for £883,000 and EE (£123,490). Lowland dairy farms received the largest grant per farm on average (£16,102), compared to £9,855 for LFA cattle and sheep farms and £8,732 for LFA dairy farms. The smallest size category of farms (0-19.9 ha) received the smallest average grant of £8,370.

Economic impacts of GES

Farm sales

As a consequence of the GES grants more than a quarter (28%) of farm businesses reported a general increase in sales with 51% reporting an increase in sales from farming specifically.

Farm expansion

The majority of members disagreed (71%) that expansion opportunities had been curtailed by GES.

Allocation of farm spending

More than 90% of respondents agreed that GES had encouraged them to undertake new capital investments. Similarly, the majority of farmers (83%) agreed that access to GES increased their scale of planned investment. Over 87% of farmers agreed that their funded project would not have happened without the grant. This suggests that GES has provided a useful tool for delivering economic development and encouraging new on-farm initiatives.

Impacts on labour

GES grants increased the annual workloads of existing employees, family members and farmers per farm per year. The workload for new employees and contractors decreased. The decrease in annual workload for contractors was greatest on LFA sheep and cattle farms. The farm type that saw the greatest increase in annual labour was lowland dairy farms.

Impacts on the wider economy

Farm expenditure

According to 77% of respondents, perceived farm viability to have increased as a consequence of receiving the grant, with 21% reporting no change. This appears to have been driven by the effect of GES grants on increased expenditure, with 52% reporting increases in expenditure. Of the 59 farms in LFA sheep and cattle, 43 reported a positive impact on changes in expenditure due to the grants.

Increased farm expenditure was spent within Welsh industries (68%), Welsh households (18%) and taxes (8%) with the remaining 6% unaccounted for due to respondent survey error.

Expenditure allocated to imports

Of the expenditure that respondents allocated to imported materials, the majority was for building materials (49%), and machinery and equipment (32%). Of these imports, 57% of spending was within the UK and Ireland; 8% reported a mixture of spending throughout the UK and European countries and 13% imported products from other European countries.

Financial effects

According to 71% of respondents, GES grants have promoted a beneficial effect on farm suppliers across all farm types. Similarly, 44% of respondents stated that farm customers and clients had experienced beneficial financial effects from the grants.

Recommendations

There were no grants in progress according to the progress report (WG, 2013). The number of WE grant types was considerably lower than for SME and EE, and it may be useful to further understand the drivers for this lack of uptake for WE grants. There were very few farms of <50 ha within the GES. There may be the potential for policy makers to consider developing grants suitable for smaller sized farms.

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1 INTRODUCTION

1.1 Background to the Glastir Efficiency Scheme

1.1.1 Background to the Glastir Scheme

The Glastir Efficiency Scheme (GES, formerly known as ACRES, the Agricultural Carbon Reduction and Efficiency Scheme) is a component of a wider Welsh Government agri-environment initiative known as Glastir. The Glastir scheme was set up as a means of merging the four existing Welsh Axis 2 agri-environment schemes (Tir Cynnal, Tir Gofal, Tir Mynydd, and the Organic Farming Scheme), into a new, single whole-farm sustainable land management initiative for farmers and land managers across Wales (WG 2014). This merger constitutes part of the Wales Rural Development Plan 2007-2013, and was made in response to the European CAP Health Check proposals (Rose 2011). The changes were driven by the need to move away from agri-environment schemes driven by paying farmers for production, to one emphasising the need for provision of environmental goods and services (known as Ecosystem Services), not usually supplied through standard market mechanisms (Wynne-Jones 2013; Reed *et al.* 2014). Under the new scheme, farmers and land managers are paid by the Welsh Government on behalf of society, for the provision of Ecosystem Services (e.g. climate change mitigation and adaptation; management of water quality and quantity; soil quality enhancement; facilitating recreational access; and strengthening social capital; (Reed *et al.* 2014). Glastir attempts to meet the need for greater integration between schemes to attain a wider and more efficient delivery of environmental services for society (Reed *et al.* 2014), whilst simultaneously improving farmers' connections to markets and strengthening rural development measures under the Welsh Rural Development Plan (WG 2014) and Axis 2 of the Common Agriculture Policy (CAP) Rural Development Pillar (Rose 2011).

1.1.1.1 Glastir objectives

The stated objectives of the Glastir scheme are (Rose 2011):

- To provide balance between the need to produce food and protect the environment;
- To be accessible to all;
- To support biodiversity, climate change and water outputs; and

- To spread money for implementing agri-environment work more widely among farmers.

1.1.1.2 Glastir scheme structure

Glastir is a five-year, whole-farm, sustainable land management scheme available to farmers and land managers across Wales. It comprises five elements: Glastir Entry, Glastir Commons, Glastir Advanced, Glastir Efficiency Grants, and Glastir Woodland Creation and Management (WG 2014). Each component is summarised below:-

Glastir Entry (All-Wales Element, AWE)

Glastir Entry is the Welsh foundation level agri-environment scheme, open to all farmers who have full management control of more than three hectares of land for the entire length of the five-year contract. Participation in the Entry level is required for eligibility to participate in all other scheme elements, with the exception of the Common Land and Woodland Creation elements. The whole-farm entry-level component is based on a points systems, where a combination of compliance with compulsory requirements, and customised choices of optional management activities, allow farmers to build up enough points to exceed the minimum eligibility threshold. It comprises three main parts: cross-compliance, the Whole Farm Code (WFC), and management options.

Cross-compliance constitutes a set of compulsory requirements that apply to all agricultural land on the farm holding. Land managers must meet standards of Good Agricultural and Environmental Condition (GAEC), concerning the protection of soil, habitats and landscape features. Additionally, cross-compliance requires farmers to meet a range of Statutory Management Requirements (SMRs) relating to the environment, public and plant health, animal health and welfare, and livestock identification and tracing. Adherence to the WFC on all land included in the contract, is a further compulsory element of Glastir Entry. The WFC comprises standards of good environmental practice, in terms of slurry spreading, manure and silage storage, rock extraction and vegetation burning. Regarding management options, farmers are required to select individual options from a list or choose from a package of options which deliver the greatest environmental benefits within a particular region.

Further to Glastir Entry, four higher level (optional) elements of the scheme are currently available:

Glastir Advanced

Glastir Advanced (previously known as the Targeted Element) was designed as an attempt to overcome reported shortcomings of previous higher-level agri-environment schemes, which were thought to have been too disparate and poorly focused to deliver significant environmental benefits (WG 2014). Candidate farms are selected for eligibility under the current Advanced scheme, on the basis of their potential for delivering environmental benefits in the key areas of soil carbon management, water quality, water quantity management, biodiversity, the historic environment, and improved access. Priority is given to applicants with the highest resulting score, based on the potential to deliver the greatest overall environmental benefit from their land.

Glastir Commons

The Glastir Commons scheme (previously named the Common Land element), was designed for farmers with Common Land rights, who are also members of a Grazing/Commoners' Association. Payments are made for adhering to either a closed grazing period over three months of the winter period (1st November to 31st March), or managing sward height throughout the year by varying stocking densities. The Glastir Commons component aims to deliver key environmental benefits relating to peatland carbon and water storage, which are important functions of Welsh Common Land.

Glastir Efficiency Scheme

Previously known as the Agricultural Carbon Reduction and Efficiency scheme (ACRES), the Glastir Efficiency Scheme (GES) provides capital grants to farmers and land managers to improve resource use efficiency and reduce the environmental imnpacts, including greenhouse gas emissions, from the agriculture sector. The scheme originally prioritised renewable energy generation outcomes, but this aspect was removed after being superseded by the UK-wide Feed in Tariffs (April 2010) and Renewable Heat Incentives (July 2013). At present, grants contributing to 40-50% of costs are available for a specific range of capital works relating to reducing on-farm energy use (Energy Efficiency), management of animal excreta and associated waste (Slurry/ Manure Efficiency), and minimising waste water generation (Water Efficiency). Grants currently available are particularly aimed at encouraging dairy farmers to take part in agri-environment schemes, in some cases for the first time.

Glastir Woodland Creation and Management

Originally functioning as a stand-alone initiative for both farmers and other woodland owners, the Glastir Woodland Creation and Management Scheme was integrated into the Glastir Scheme in January 2013. It was developed in response to the Climate Change and Land Use Report (Glastir Independent Review Group, 2011). This element of Glastir currently provides financial support to both farmers and non-farmers for managing existing continuous woodlands larger than 0.5 ha in size. Capital and multi-annual payments are provided in support of managing existing woodland and creation of new woodland, including income foregone as a result of change in land use. Payments are prioritised for delivering the following: managing soils to help conserve carbon stocks and reduce soil erosion; improving water quality; managing flood risks; conserving and enhancing wildlife and biodiversity; managing and protecting landscapes and the historic environment; and providing new opportunities to improve access and understanding of the countryside.

1.2 Socio-economical trickle down impacts in rural areas

Rural areas in Wales account for 82% of the total area and contain one third of the total population (OECD 2011). Agri-environment schemes are implicit in their support of agricultural economies, reflecting an understanding of the defining relationship between farming and the rural landscape (Davies-Jones 2011). Agriculture plays a dominant role in land-use, and in some regions it continues to play a pivotal role in the local economy (OECD 2010). Without adequate financial support, farmers may be unable to continue to farm, resulting in a loss of skills and neglected land, with subsequent environmental and socio-economic implications beyond the farm gate (e.g. less money for the local economy, movement of the young population sector to cities). Consequently, this poses a threat to the Welsh tourist industry, culture and language (Davies-Jones 2011).

Glastir seeks to move the basis of payment for farms from production-based to environmental outcome-based payments, whereby farmers are paid for providing environmental goods and services (Wynne-Jones 2013). Agricultural policies are important for those who obtain their livelihood from the agricultural sector, not only from farming but also in related upstream and downstream industries, or through activities associated with agriculture (e.g. forestry and tourism). The significance of agriculture for the rural economy can be amplified through linkages to agro-food industries and employment in these industries (OECD 2010; OECD 2011). The trickledown effect of agriculture in rural areas is important for the continuation of a sustained rural community, one which can potentially be enhanced by agricultural policies such as Glastir, by promoting 'sustainable intensification' on farms (Caballero 2011). There are many potential direct and indirect trickledown effects. A simple example offered by Glastir would be the construction of a new manure shed as a result of extra funding provided by the GES, whereby raw materials are bought locally, and local workers contracted in to construct the manure shed. On a larger scale, better land management could lead to increased biodiversity, increased tourism and increased spending in local communities. The key feature is that on-farm developments should have a beneficial trickledown effect to the wider rural community.

2 PROJECT AIMS AND OBJECTIVES

This study aimed to improve understanding of the current status of grants within GES and to evaluate the wider economic benefits to farmers and the Welsh economy.

2.1 Objectives

The key objectives of this project were:

- to summarise the current status of approved GES grants, and grants in progress;
- to assess the impact of GES grants on economic outputs and efficiency of farms;
- to determine the effect of GES grants on employment ;
- to better understand the impacts of GES grants on the wider economy.

3 METHODS

3.1 Survey structure

The survey comprised 33 questions, which aimed to assess the effect of GES grants on economic output and efficiency, farm spending, farm labour and the wider economy for each farm. To alleviate respondent burden when completing the survey, 25 Likert Scale questions were included, while the remaining eight questions were of an open-ended format. Where possible, answers to open-ended questions were grouped for the purposes of analysis. A copy of the survey is provided in Annex 1 (at the end of this report). All proportions were rounded-up to the nearest whole integer.

3.2 Data collection

All farmers from the 157 GES-participating farms were invited to complete the survey, initially by postal contact, followed by telephone calls made within a month of initial contact. Data was collected between November 2013 and July 2014.

Farms types and sizes follow the DEFRA categorisation of robust farm types (DEFRA 2010).

4 RESULTS

4.1 Participant response rate and characteristics

The survey participation rate attained 75% of the total GES member population (120 farmers agreed to complete the survey, from the original 157 Glastir Entry members invited).

4.1.1 GES-participating farms

Of the 157 farms awarded GES grant funding, the majority were LFA cattle and sheep farmers (93 farms), while the remainder were primarily dairy farmers (34 lowland dairy, and 14 LFA dairy farms). Only 16 farms were designated to other farm type categories, including 4 farms of unspecified type (Fig. 4.1).

Only three participating farms were smaller than 50 hectares. Most farms were 50 to 199.9 ha in size (92 farms), while the remainder were more than 200 ha in size (58 farms; Fig. 4.2). The average size of surveyed farms (189 ha) was larger than both the average farm size for the 2378 farms in the Glastir Entry level scheme (93 ha), and the average size of all Welsh agricultural holdings (41 ha; (WG 2014)).

4.1.2 Survey-participating farms

The distribution of survey respondents amongst both farm type and farm size categories closely matched the distribution of GES-participating farms, resulting in a robust representation of almost all classes of farms (Fig. 4.2.). In terms of farm type, LFA dairy and lowland cattle and sheep farms were slightly under-represented (approximately half of farmers from each group took part in the survey). In the farm size categories, the larger farms were slightly less well represented in percentage terms than the smallest farms (up to 19.9 ha in size).

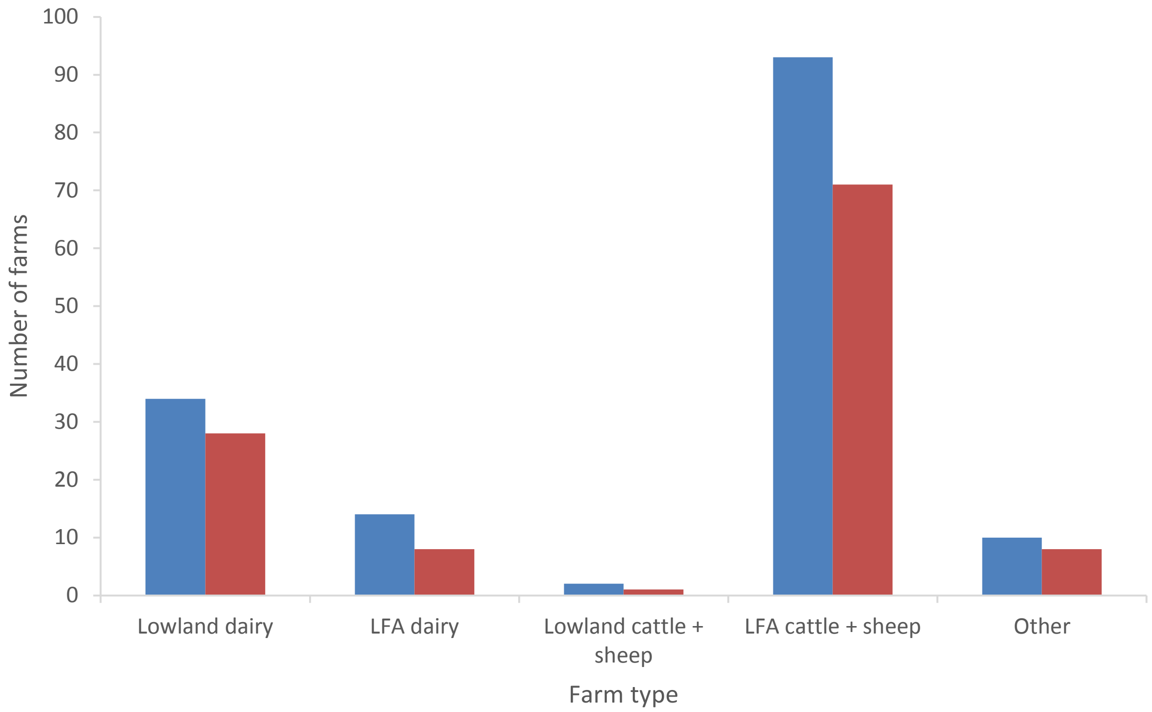

Figure 4.1. Number of participating farmers in GES (blue bars) and the survey sample (red bars), by farm type. ‘Other’ farm types include mixed livestock and cropping, and specialist poultry farms.

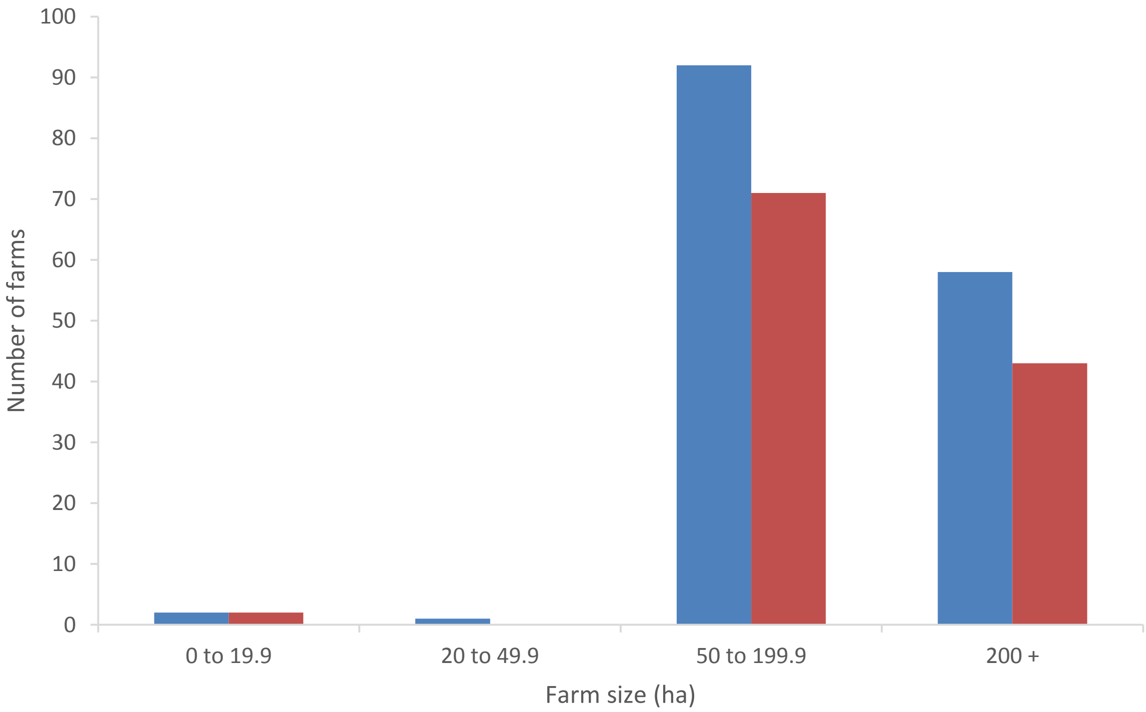

Figure 4.2. Number of participating farmers in GES (blue bars) and the survey sample (red bars), by farm size (ha).

4.2 Employment characterisation

The majority of those employed on the farms were family workers, with a strong bias towards full-time male workers (34% of all workers; Table 4.1.). Full-time male workers worked the longest average hours per week (71 hours), and were employed on the largest number of farms (113 farms). Full-time female family workers worked the second-longest hours per week (50 hours), but in lower numbers (49 workers), and on fewer farms (43 farms). In addition to family workers, many farms also employed additional (again, predominantly male) full-time and part-time workers. In contrast to family workers, female employees worked a similar number of hours per week to male employees.

Table 4.1: Proportion of workload by employee type

Employee type	Total employees	Farms with employee type	Average hours per employee per week
Full-time male family workers	181	113	71
Full-time female family workers	49	43	50
Part-time male family workers [1]	51	37	29
Part-time female family workers [1]	46	37	19
Seasonal male family workers	30	16	-
Seasonal female family workers	10	10	-
Full-time male employees	45	25	46
Full-time female employees	4	3	43
Part-time male employees [1]	71	36	18
Part-time female employees [1]	2	2	22
Seasonal male employees	34	17	-
Seasonal female employees	5	4	-

Notes: [1] Part-time workers are assumed to work up to 30 hours per week.

Both family and non-family seasonal workers were also employed by farms, but made up a much smaller proportion of workers than full or part-time workers.

4.3 Grant allocation

4.3.1 Approved grants

The grants allocated to farms were categorised into the following three types: Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE). A total of 383 grant requests were approved across the 157 GES participants (Fig. 4.3 and 4.4). Of these, 327 were awarded for SME measures, 39 were awarded for EE measures, and 17 were awarded for WE measures. Most individual grants were awarded to LFA cattle and sheep farms (58.7%), with a further 23.0% awarded to lowland dairy farms (Fig. 4.3). Farms of 50 to 199.9 ha in size received the greatest number of grants (61.6%); the majority of remaining grants were allocated to farmers > 200 ha in size (33.4%; Fig 4.4).

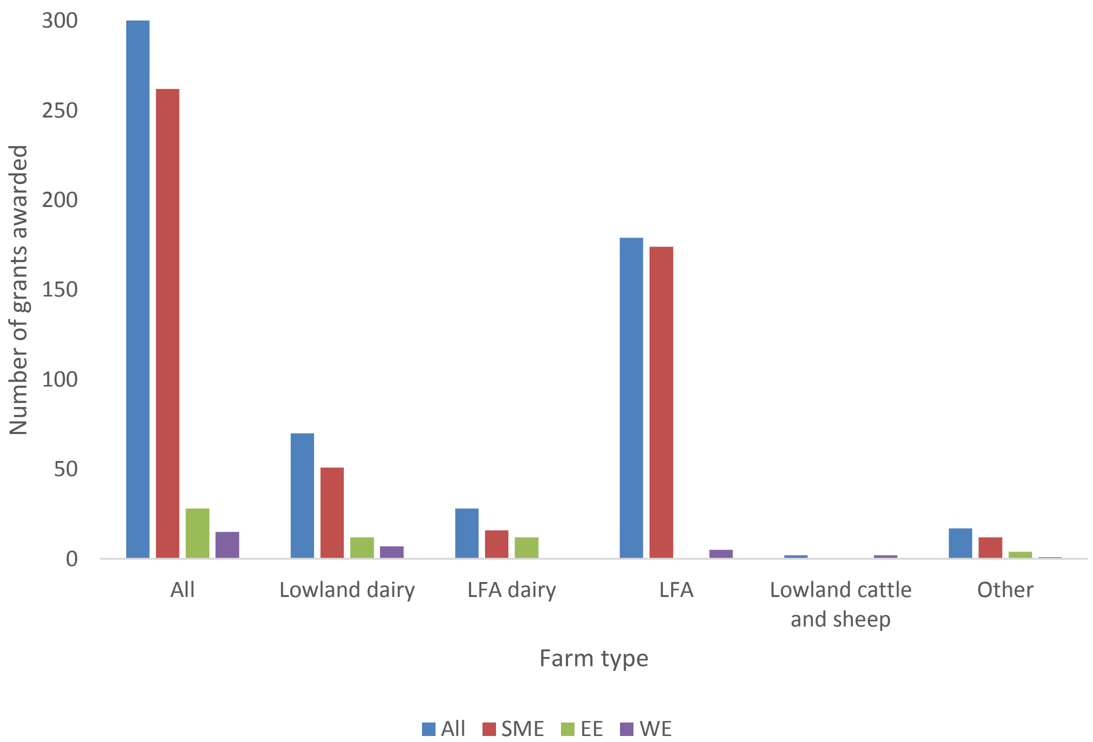

Figure 4.3. Grants approved for GES-participating farms, by farm type and grant type. Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE)

A total of 305 grants were approved across the survey sample farms, of which the majority were SME grants (86%; Table 4.2). With respect to farm size, the largest portion of grants had been approved for larger farms, primarily in the 50 to 199.9 ha size category (62%). Most of the approved grants were allocated to LFA cattle and sheep farms (59%), while lowland dairy farms received 23% of grants.

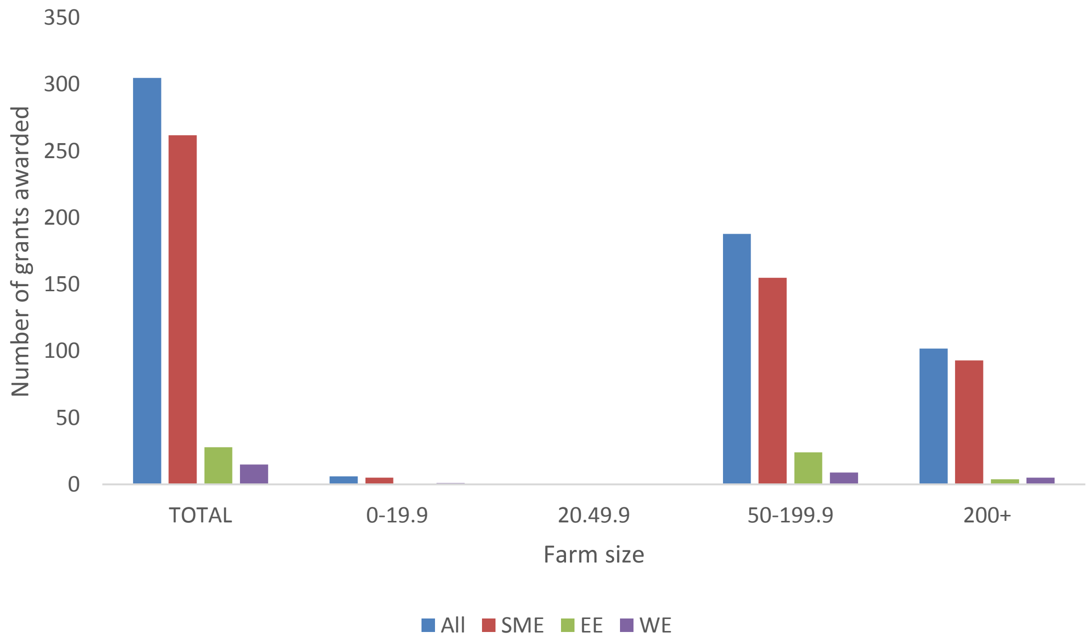

Figure 4.4. Grants approved for GES-participating farms, by farm size and grant type. Slurry and Manure Efficiency (SME); Energy Efficiency (EE) and Water Efficiency (WE)

Table 4.2. Grants approved by farm size and type (with proportion of total approved grants in parentheses)

Farm size and type	All	SME	EE	WE
TOTAL	305 *(100%)*	262 *(86%)*	28 *(9%)*	15 *(5%)*
0 to 19.9 ha	6 *(2%)*	5 *(2%)*	0 *(0%)*	1 *(0.3%)*
20 to 49.9 ha	0 *(0%)*	0 *(0%)*	0 *(0%)*	0 *(0%)*
50 to 199.9 ha	188 *(62%)*	155 *(51%)*	24 *(8%)*	9 *(3%)*
200+ ha	102 *(33%)*	93 *(30%)*	4 *(1%)*	5 *(2%)*
Unknown size	9 *(3%)*	9 *(3%)*	0 *(0%)*	0 *(0%)*
Lowland dairy	70 *(23%)*	51 *(17%)*	12 *(4%)*	7 *(2%)*
LFA dairy	28 *(9%)*	16 *(5%)*	12 *(4%)*	0 *(0%)*
LFA cattle and sheep	179 *(59%)*	174 *(57%)*	0 *(0%)*	5 *(2%)*
Lowland cattle and sheep	2 *(1%)*	0 *(0%)*	0 *(0%)*	2 *(1%)*
Other	17 *(6%)*	12 *(4%)*	4 *(1%)*	1 *(0.3%)*
Unknown type	9 *(3%)*	9 *(3%)*	0 *(0%)*	0 *(0%)*

4.3.2 Grants in progress

By October 2013, the overall percentage of grants in progress as a proportion of approved grants was 33% (Table 4.3; (WG 2013)). More than half (57%) of approved EE grants were in progress by the same date, but only 32% of approved SME grants. No approved WE grants were in progress. No EE grant money had been paid to LFA cattle and sheep farms. Overall, the majority of grants in progress were received by farms in less favoured areas (LFA) (70%), and by farms of 50 to 199.9 ha in size (68%).

Table 4.3. Grants in progress (as a proportion of category's approved grants in parentheses)

Farm size and type	All	SME	EE
TOTAL	100 *(33%)*	84 *(32%)*	16 *(57%)*
0 to 19.9 ha	2 *(33%)*	2 *(40%)*	0 *(0%)*
20 to 49.9 ha	0 *(0%)*	0 *(0%)*	0 *(0%)*
50 to 199.9 ha	68 *(36%)*	53 *(34%)*	15 *(63%)*
200+ ha	27 *(26%)*	26 *(28%)*	1 *(25%)*
Unknown size	3 *(33%)*	3 *(33%)*	0 *(0%)*
Lowland dairy	19 *(27%)*	13 *(25%)*	6 *(50%)*
LFA dairy	13 *(46%)*	6 *(38%)*	7 *(58%)*
LFA cattle and sheep	57 *(32%)*	57 *(33%)*	0 *(0%)*
Lowland cattle and sheep	0 *(0%)*	0 *(0%)*	0 *(0%)*
Other	8 *(47%)*	5 *(42%)*	3 *(75%)*
Unknown type	3 *(33%)*	3 *(33%)*	0 *(0%)*

4.3.3 Grant money received

The total monetary value of grants received by October 2013 was £1,006,490, of which £883,000 was awarded as SME grants and £123,490 as EE grants (Table 4.4.). The average grant value awarded per project was £10,988. Lowland dairy farms tended to receive larger grants, with an average of £16,103 per individual grant compared to an average grant value of £9,855 for LFA cattle and sheep farms. Farms with 50 to 199.9 ha of land received the largest average grant of £11,534, with farms of 200+ ha receiving £10,005 on average. Farms in the 0 to 19.9 ha category received the lowest average grant (£8,370).

Table 4.4. Total and average monetary values of grants by grant type, farm type and farm size

Farm size and type	Total (£)			Average per grant (£)		
	ALL	SME	EE	ALL	SME	EE
0-19.9 Ha	16, 741	16, 741	-	8, 370	8, 370	-
20.49.9 Ha	-	-	-	-	-	-
50-199.9 Ha	703, 770	583, 421	120, 348	11, 534	11, 875	8, 827
200+ Ha	258, 658	255, 515	3, 143	10, 005	10, 409	3, 143
Unknown size	27, 324	27, 324	-	10, 228	10, 228	-
Lowland dairy	257, 054	225, 848	31, 205	16, 103	19, 413	4, 775
LFA dairy	89, 759	63, 884	25, 875	8, 732	12, 942	2, 988
LFA c+s [1]	540, 459	540, 459	-	9, 855	9, 855	-
Lowland c+s [1]	-	-	-	-	-	-
Other	91, 897	25, 486	66, 411	10, 606	7, 201	20, 822
Unknown type	27, 324	27, 323	-	10, 228	10, 228	-
Total	1, 006, 493	883, 001	123, 491	10, 988	11, 298	8, 117

[1] *Less favoured area cattle and sheep.*

4.4 Economic impacts of Glastir Efficiency Scheme

By October 2013, 60 of the 120 survey farms had received approved funding for capital investments, and of the 157 farms to whom the survey was sent, a further nine farmers declined to complete the questionnaire as they had not yet received the grant. The following sections describe the impact on the Welsh economy of the Glastir Efficiency Scheme, based up on the 120 completed surveys.

4.4.1 Economic outputs and efficiency

Respondents considered that the GES grants increased the value of sales for 28% of farms, while the majority of farmers (63%) suggested that the value of sales had not changed (Fig. 4.5). Only a small proportion of farmers (3%) said that the value of their sales had decreased since obtaining grants.

When considering the overall impact of GES grants on sales from farming, most farmers reported no change (48%), while a further 33% reported 'little positive impact' and almost a fifth of respondents stated an 'important positive impact' (18.3%) (Fig. 4.6.). Very few

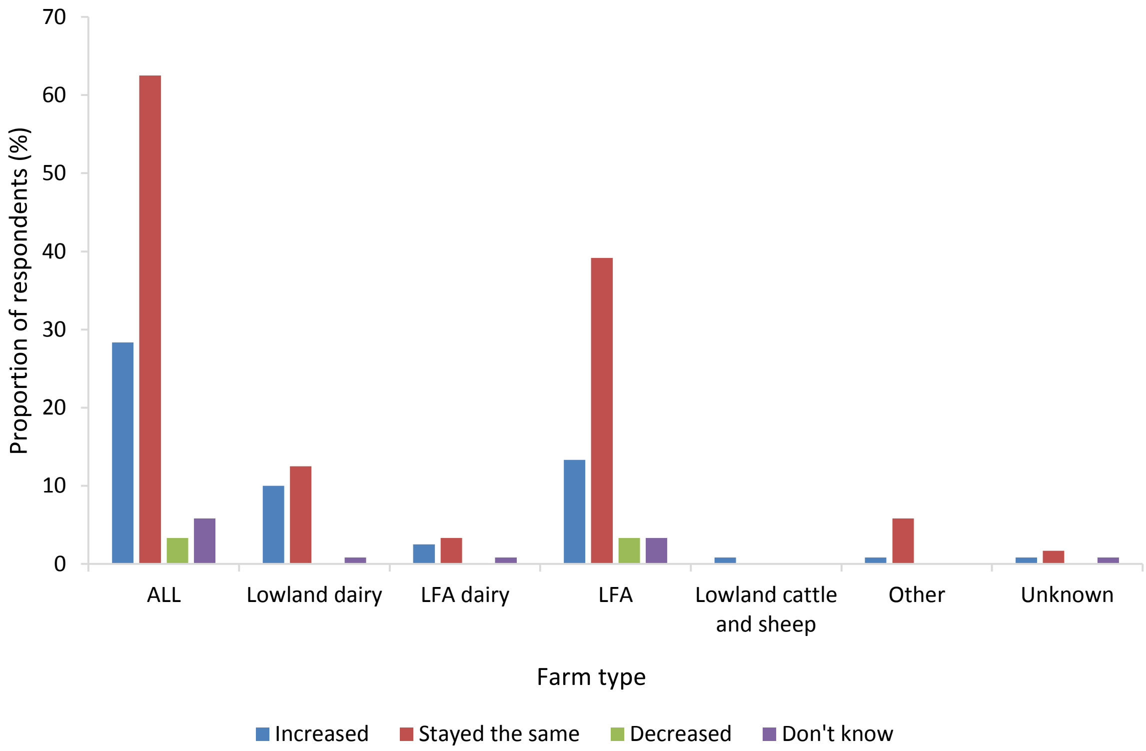

Figure 4.5. Impact of receiving GES grants on the value of sales

farmers said GES grants had had a negative impact on sales (< 1%).

4.4.2 Allocation of spending

Access to GES grants appears to have encouraged new capital investment by farmers in all farm type categories (Fig. 4.7). It was agreed by 65% and strongly agreed by 28% that the grant had encouraged them to undertake new capital investments, whilst only 5.9% of

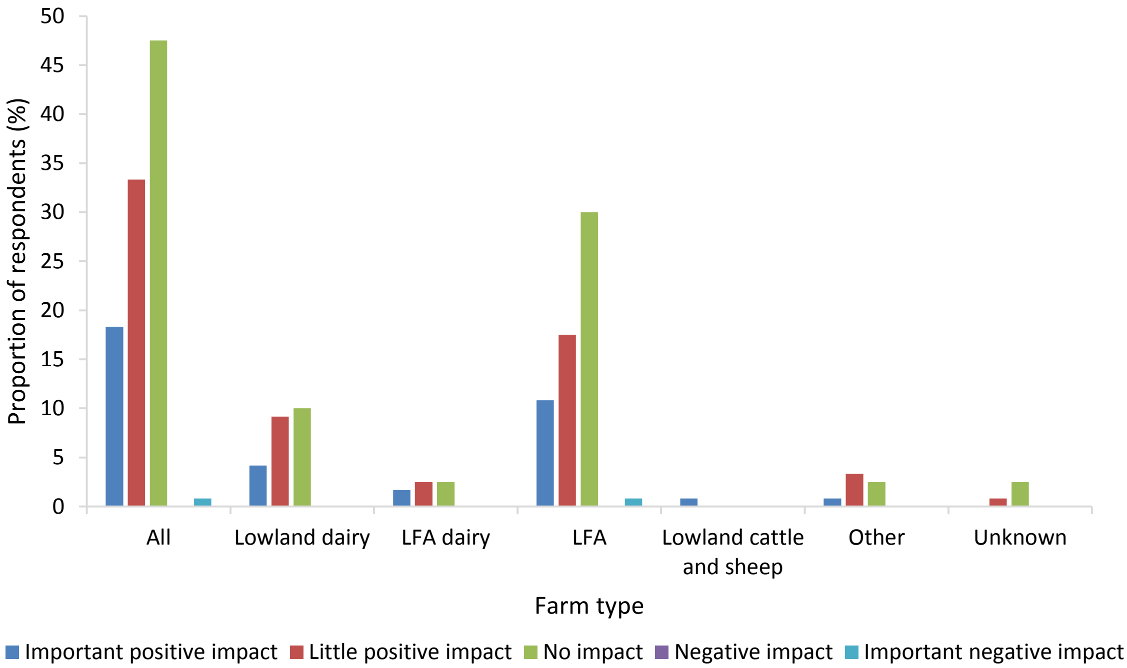

Figure 4.6. Impact of GES grants on sales from farming.

farmers disagreed with this statement.

Access to GES grants appears to have helped farmers to increase the scale of their planned investments, with 16% strongly agreeing, and 67% agreeing with the statement ‘Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to increase the scale of planned investments’. Only 12% of respondents disagreed or strongly disagreed with the statement (Fig. 4.8). More than half of the respondents (55%) agreed, and one third (32%) strongly agreed that the funded project would not have happened without the grant, while

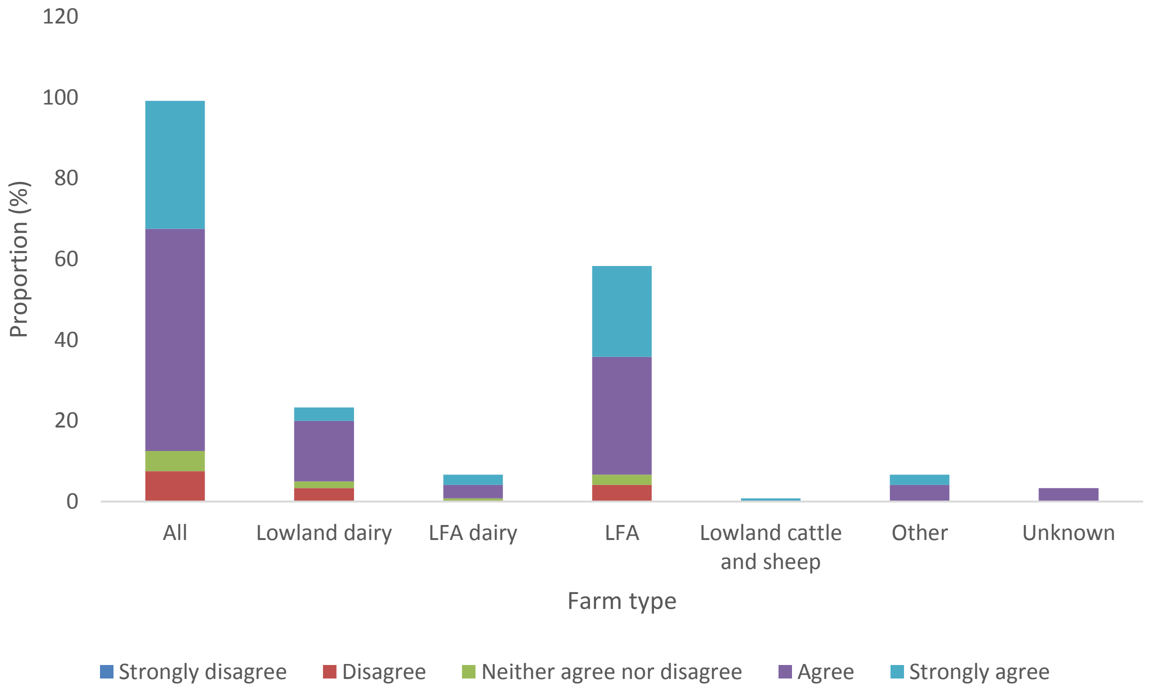

Figure 4.8. Degree of agreement that funded projects would not have happened without receiving GES grants.

only 8% of farmers disagreed with that this was the case (Fig. 4.8).

More than half of respondents reported the grants having no impact on all but two sectors of farm expenditure. Fertiliser annual expenditure was positively impacted by the grants on 75% of farms (Fig. 4.9). Labour expenditure was positively impacted in 50% of cases, and 40% of contractor expenditure. Negative impacts were reported by a minority of farmers (2-7%, depending on sector), with the largest negative impacts for contractors and building materials expenditures (7% of respondents in both cases), while the least frequently reported negative impact was on veterinary fees (2%).

Only a few respondents were able to provide monetary values for reduced expenditure. Spending on fertilisers was reduced by an average of £3,291 per farm (46 farms; range from £500-£20,000), on-farm purchases by an average of £2,375 (22 farms), and chemicals by an average of £425 per farm (4 farms).

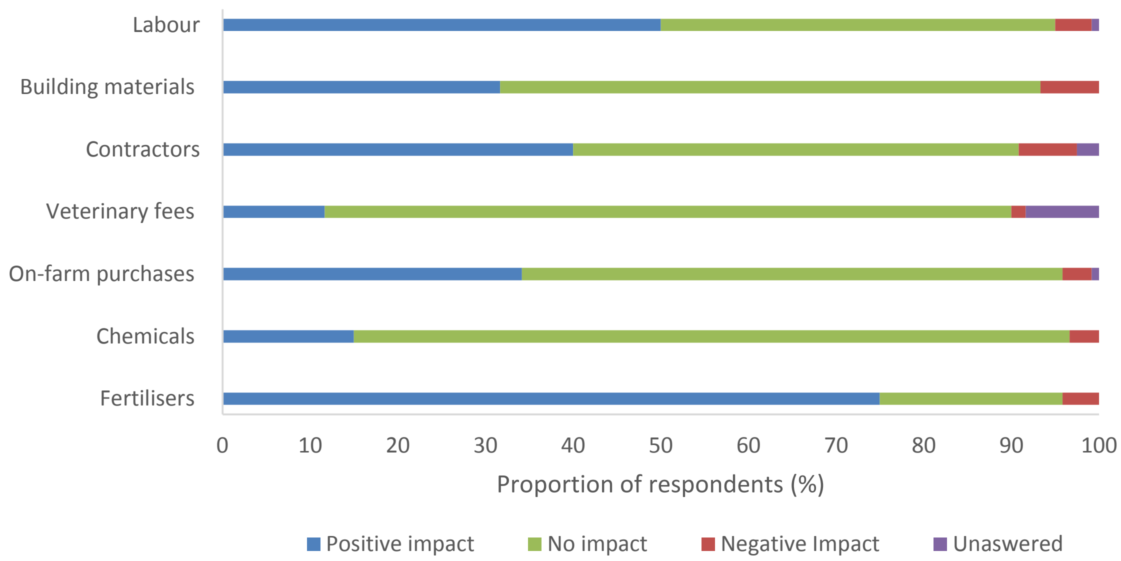

Figure 4.9. Respondents' perception of grant impact on different sectors of on-farm expenditure.

4.4.3 Impacts on labour

On average, existing employees, family members and farmers found their annual workloads increased as a result of receiving GES grants, when aggregated across farm types (Fig. 4.10), possibly as a result of on-farm decisions to maximise the proportion of GES funding allocated to material purchases by minimising direct labour costs. In contrast, a net decrease in annual labour-days was experienced by contractors and new employees averaged across all farm types. However, an average decrease in annual labour-days was experienced on LFA cattle and sheep farms (71 farms), for contractors (3.3 labour days per farm per year), and for new employees (0.8 days per farm per year). This appeared to be countered by an annual increase of annual labour-days on lowland dairy farms (28 farms) for both existing employees (10.7 days per farm per year), and for contractors (4.3 days per

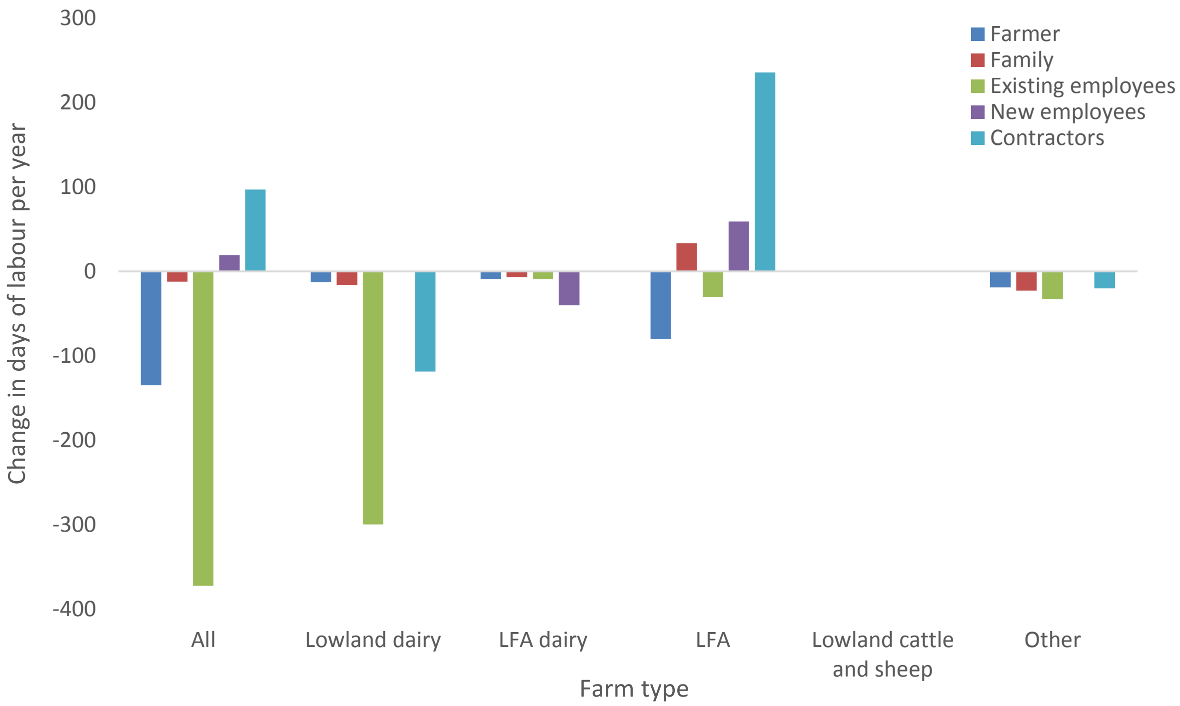

Figure 4.10. Net annual change in days of labour per year by farm type.

farm per year).

The impact of grants on labour varied across farm size categories. No change in annual labour-days worked was reported from farms of less than 50 ha in size (omitted from Fig. 4.11). Farms of 50 to 199.9 ha in size experienced an overall increase in workload, for all worker categories, and for existing employees in particular (Fig. 4.11). Conversely, farms of more than 200 ha in size showed a decrease in annual labour-days across all categories except for ‘existing employees’, with contractors losing the greatest number of additional days of labour (5 days per farm per year).

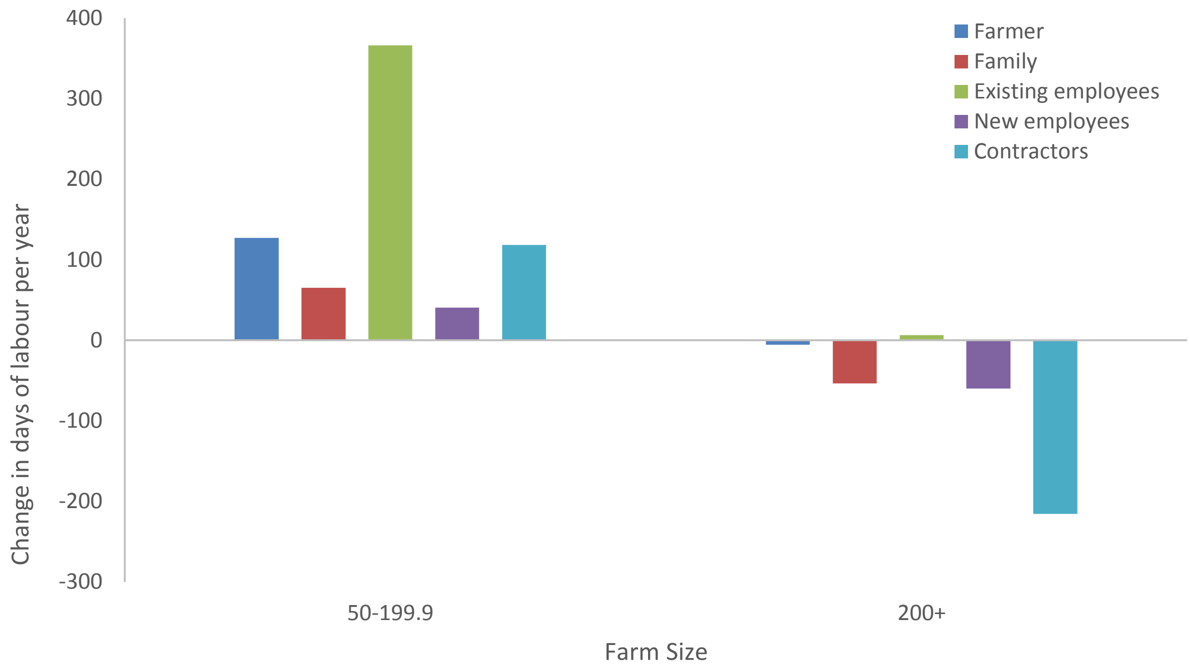

Figure 4.11. Net annual change in days of labour per year by farm size (ha).

Few respondents reported that their weekly working hours would have been different without GES grants. An increase in labour-hours worked per week on receiving grants was only experienced by 12 farmers (25.7 hours per week), while 10 farmers stated that they would have worked an additional 18.6 hours per week, had they not received GES grants.

4.4.4 Impacts on the wider economy

4.4.4.1 Farm viability

Farm viability was perceived by 77% of respondents to have increased due to GES grants, while 21% stated that farm viability remained unchanged (Fig. 4.12). As a proportion of the respondents within each farm type, lowland cattle and sheep farms and lowland dairy farms most frequently reported a perceived increase in viability (100% and 88% of respondents respectively). None of the farmers in the survey reported a perceived decrease in farm business viability after receiving GES grants.

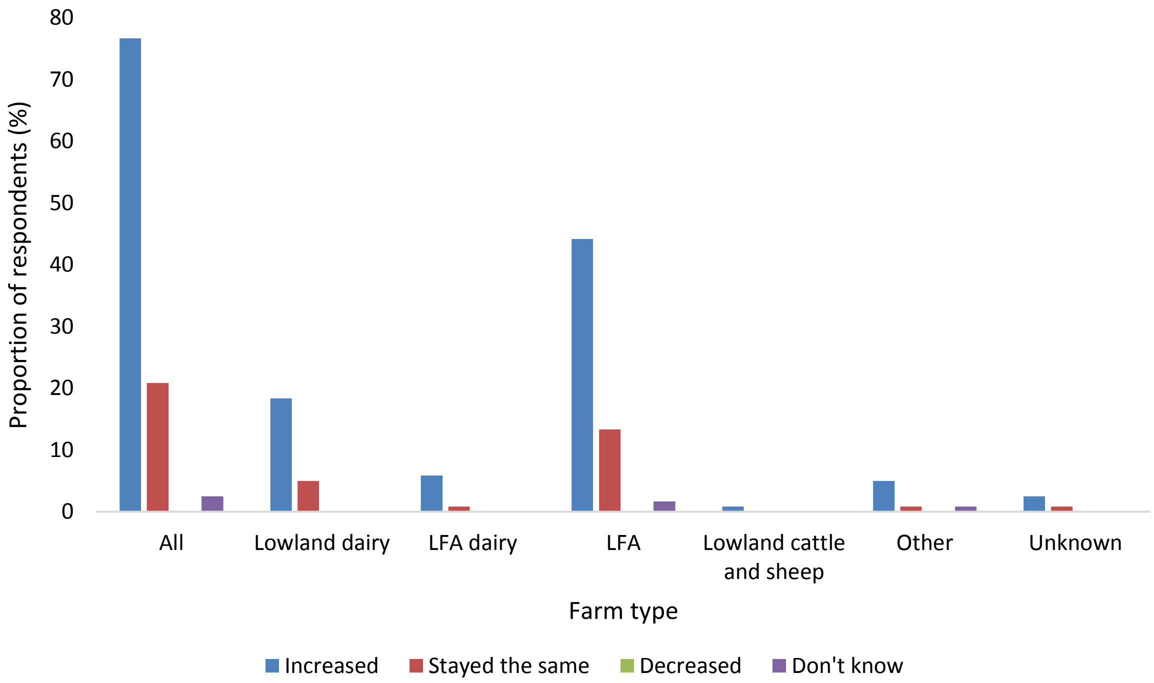

Figure 4.12. Impact of receiving GES grants on perceived farm viability

4.4.4.2 Changes in farm expenditure

Grants appear to have had a positive impact on changes in expenditure, with 68% of respondents experiencing positive impacts (i.e. improved farm infrastructure and decreased personal expenditure), and 9% strongly positive impacts (Fig. 4.13). No impact on changes in expenditure was reported by 11% of farmers. The remaining 13% of respondents reported a negative impact, but only one farmer perceived a strongly negative impact on expenditure.

Farmers were asked whether they agreed that farm expenditure had increased after receiving GES grants. Of those who answered the question (98% of survey respondents), 42% agreed, and 11% strongly agreed, whilst 42% disagreed or strongly disagreed with this statement (Fig. 4.14).

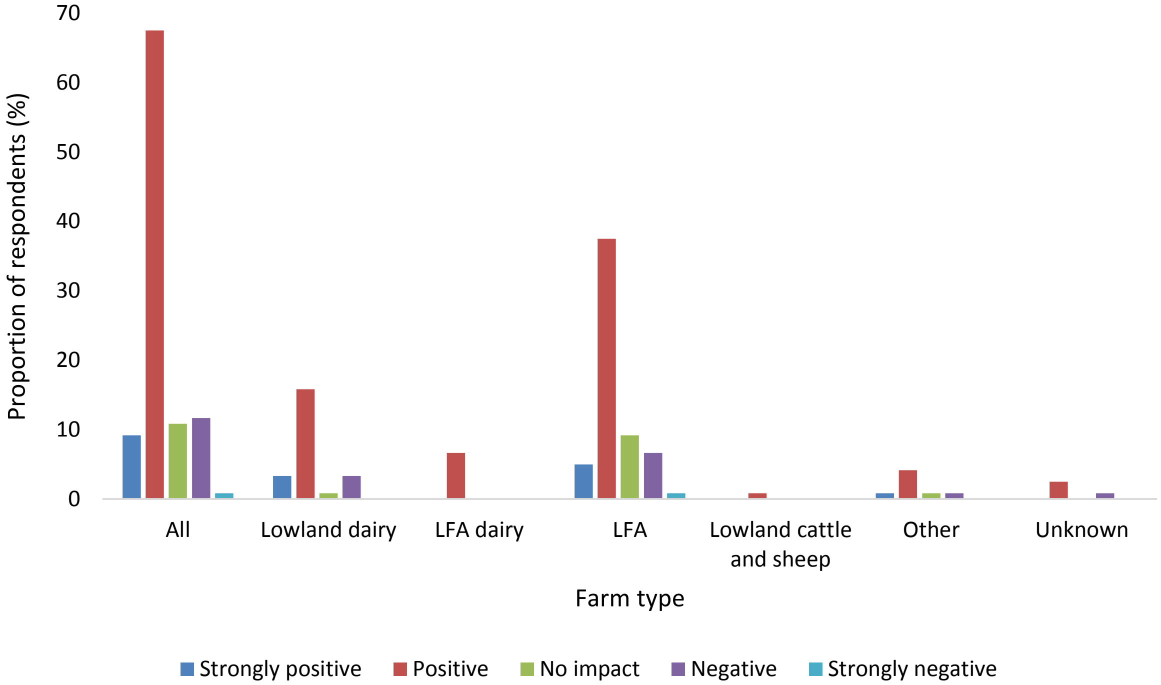

Figure 4.13. Impact of GES grants on farm expenditure.

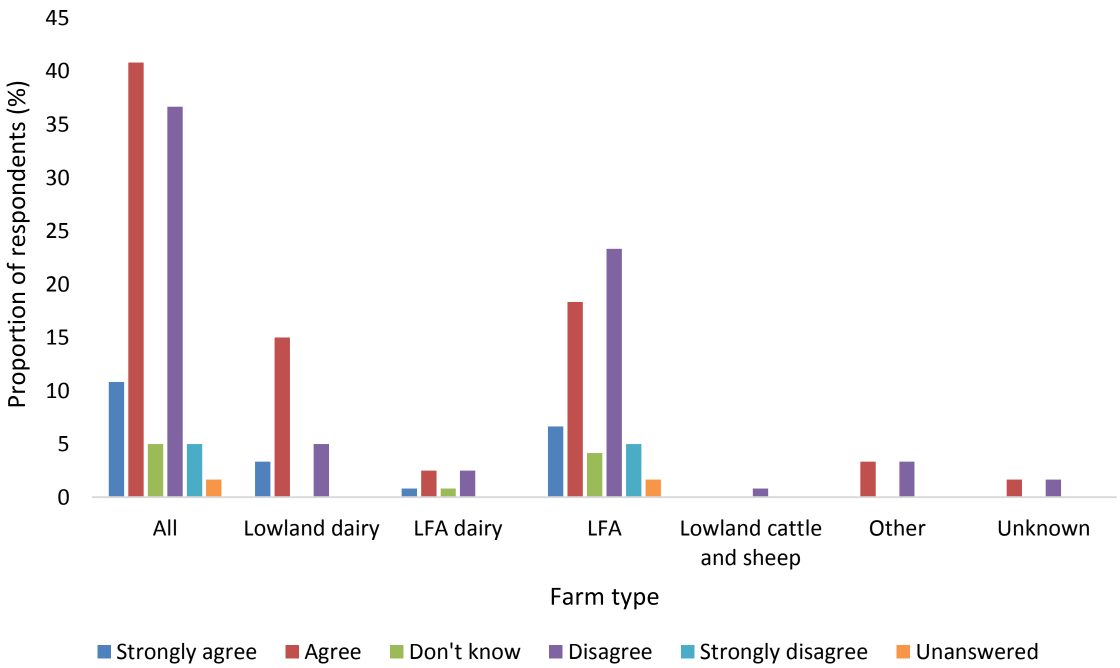

Figure 4.14. Proportion of farmers reporting an increase in expenditure after receiving GES .grants

Of the farmers reporting an increase in expenditure, 58% answered the follow-up question detailing how the additional money was spent. Increased expenditure was distributed primarily to Welsh industries (68%), Welsh households (18%) and taxes and imports (8%; Fig. 4.15). The remaining 6% of expenditure was unaccounted for[1]

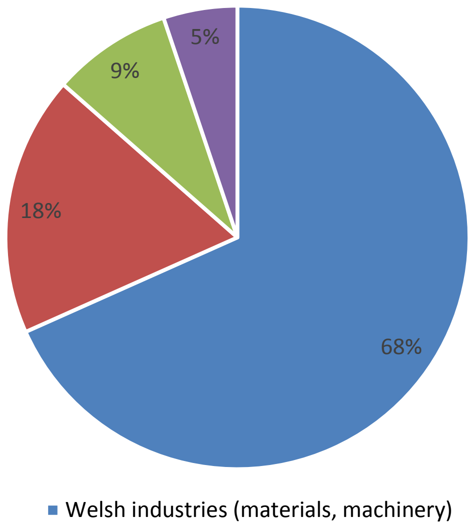

Figure 4.15. Allocation of increased expenditure following receipt of GES grants.

Of the respondents that had grants in progress (60 farms), 87% spent money on building materials (52 farms), 65% on machinery and equipment (39 farms), and 45% on labour (27 farms; Table 4.6). Only a small proportion of farms had spent money on rental and hire of equipment (13%) or repairs (5%). (Table 4.5).

Table 4.5. Total and average farm expenditure (£) across sectors, for GES-participating farms.

	Building materials	Machinery or equipment	Rental and hire	Repairs	Labour
Number of farms	52	39	8	3	27
Total expenditure	561,381	309,931	92,792	4,666	136,529
Average spent per farm	10,796	7,947	11,599	1,555	£5,057

[1] Here, 'unaccounted for' represents respondents whose answers to this question represented less than 100%, implying that some of their expenditure was allocated towards something unrepresented by the other three sectors

*4.4.4.3 Expenditure on taxes and imports*A small number of open-ended questions were included in the survey regarding expenditure allocated to taxes and imports. When asked what proportion of the expenditure was allocated specifically to taxes, 49% of participants stated 0%, with a further 17% not knowing, and 8% declining to answer (Fig. 4.16). Of those able to give an estimate, 16% recorded allocating 20% of expenditure towards taxes, and a further 5% of respondents recorded less than 20%. Five per cent of respondents reported that more than 20% of their expenditure was allocated to tax.

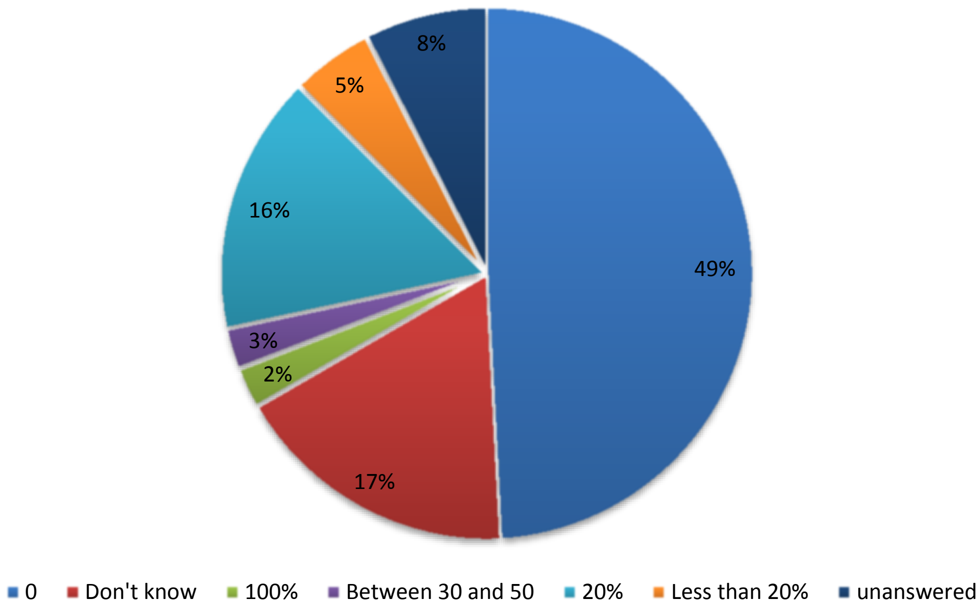

Figure 4.16. Proportion of expenditure allocated to tax per farm.

Thirty-seven respondents stated they had spent money on imports. Expenditure was primarily allocated to building materials (35% of farmers) and machinery and equipment (32% of farmers; Fig. 4.17). A small amount of expenditure was allocated to slurry equipment (14%) or animal care (feed, veterinary care; 5%). The remaining 14% of farmers

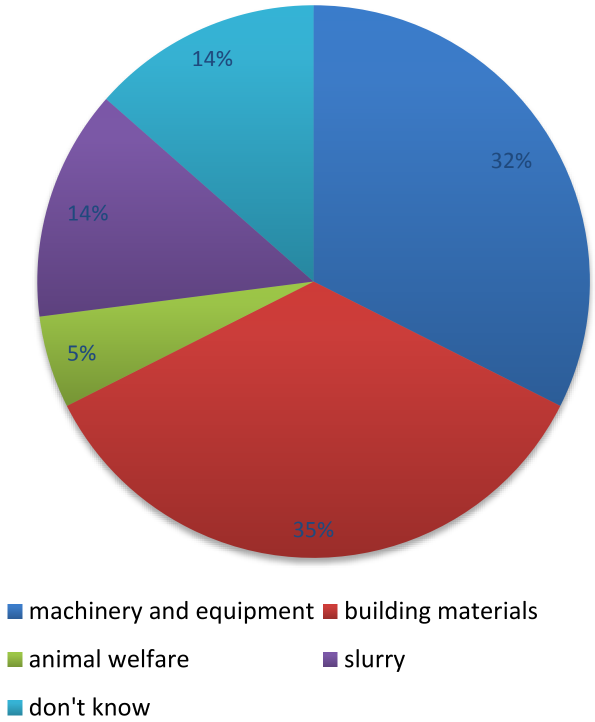

Figure 4.17. Farmer expenditure on imported products.

did not know which imported products they had spent money on.

Of the expenditure allocated to imports, 57% of respondents purchased products from within the UK and Ireland; 14% from other European countries; and 8% from within Europe including the UK. The remaining 22% of respondents did not know the origin of their imports (Fig. 4.18).

4.4.4.4 Upstream and downstream economic impacts

Overall, 71% of respondents claimed that the GES grants financially benefitted their suppliers, while only 2% of respondents reporting a perceived negative financial effect on suppliers. One fifth of respondents (19%) were unable to offer an estimate (Fig. 4.19).

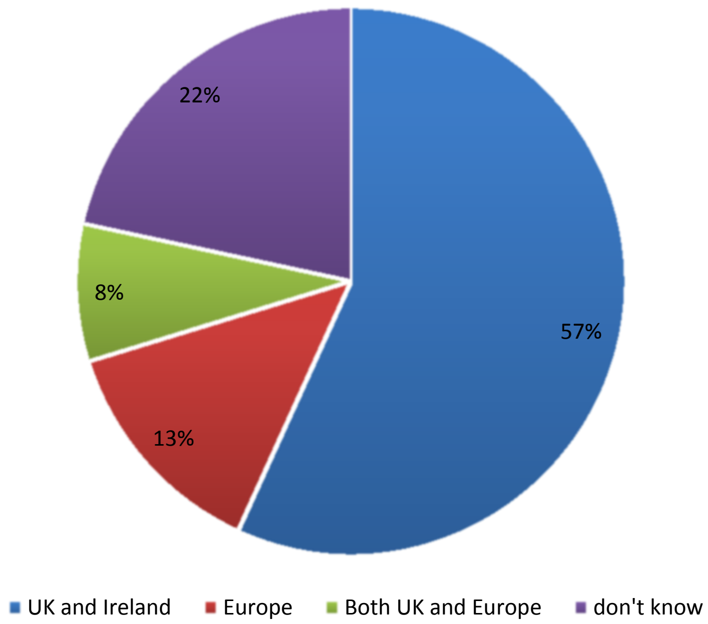

Figure 4.18. Country of origin of respondents' imported products.

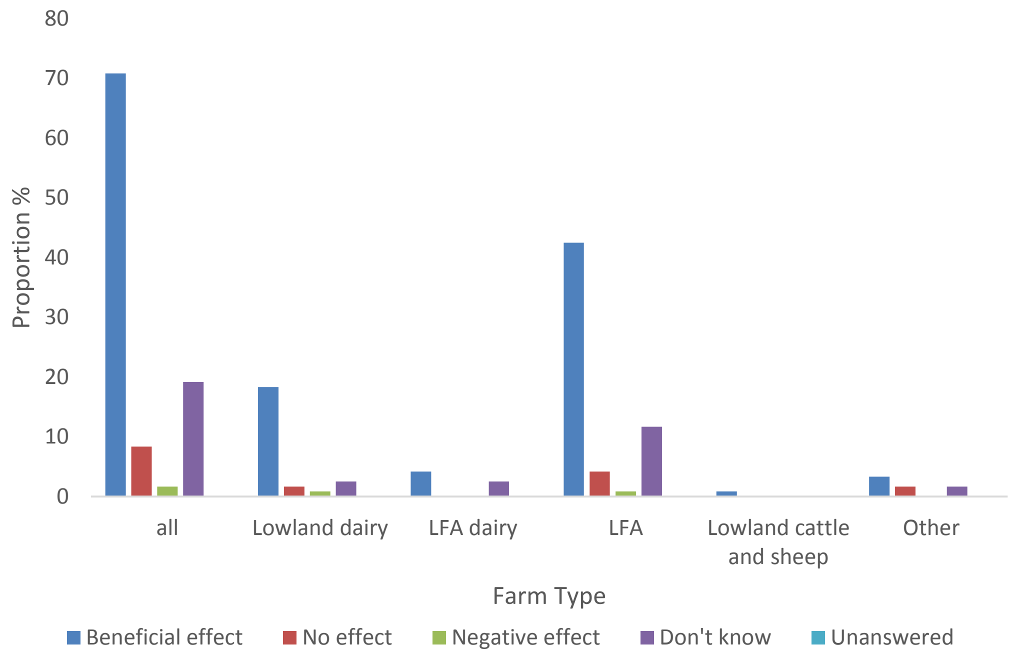

Figure 4.19. Perceived financial impact of GES grants on farm suppliers.

Most respondents reported that the financial impact of GES grants on their customers was beneficial (44%), although an almost equal proportion of respondents estimated no effect on their customers (38%; Fig. 4.20). Thirteen per cent of respondents declined to comment.

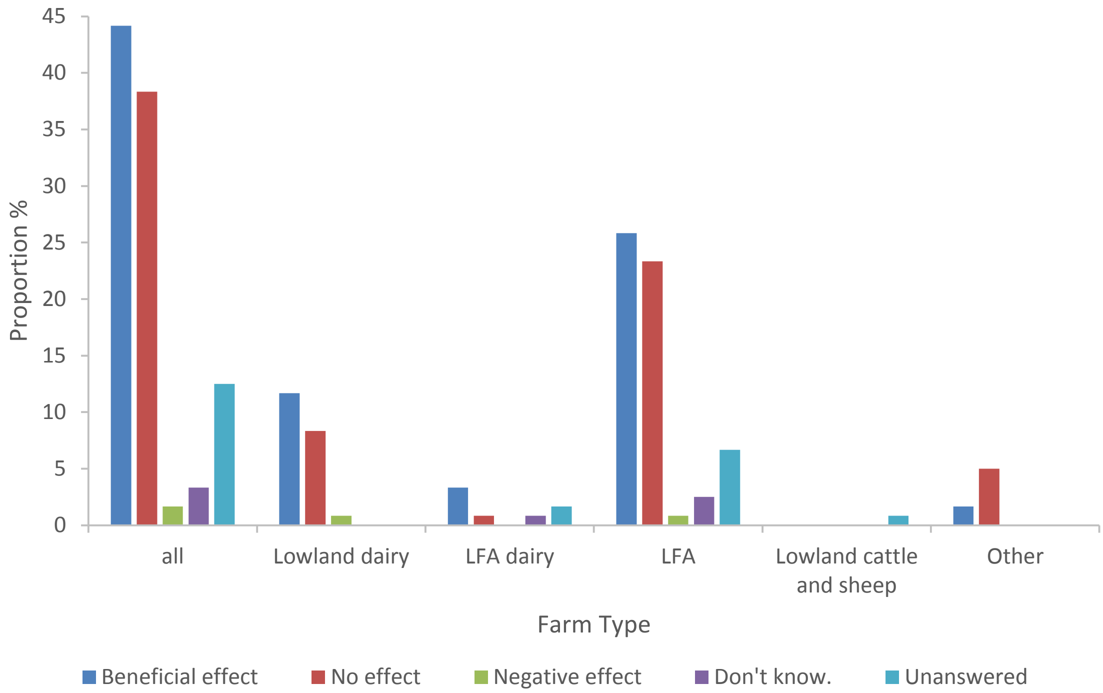

Figure 4.20. Perceived financial impact of GES grants on participating farms' customers and clients.

The perceived effect on farmers’ competitors was smaller still, with only 13% of farmers claiming a beneficial effect on competitors, and the majority (54%) reporting no perceived effect (Fig. 4.21). A relatively large proportion of respondents did not answer this question (22%), while a further 8% stated they did not know the answer. Only 3% of respondents reported that GES grants had a negative effect on competitors.

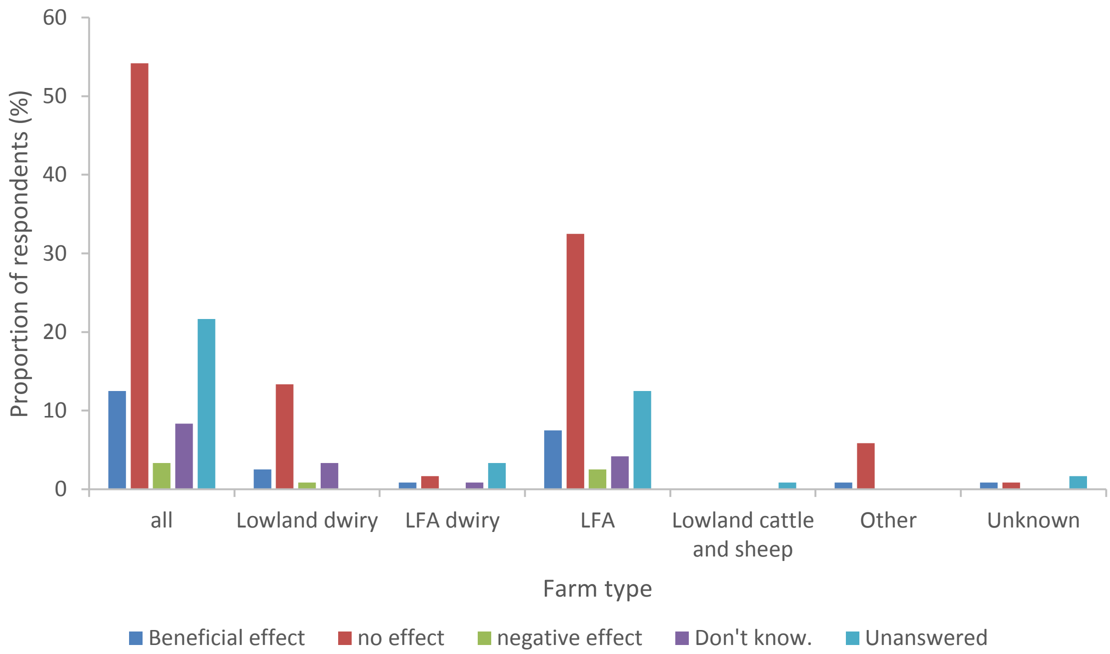

Figure 4.21. Perceived financial impact of GES grants on participating farms' competitors.

4.4.5 Farm efficiency

The majority of respondents (70%) stated that they could do more for themselves to increase efficiency on their farms, with almost a third of these (26% of all respondents) giving examples of how they could increase efficiency (Table. 4.6). The most popular specific suggestions for increasing efficiency, related to improvements in equipment (8% of respondents), land use or quality (8%), or energy and electricity use (4%), although it is possible there may be some cross-over between these categories implicit in farmers' responses. Less than a quarter of farmers (23%) reported that there was nothing more they could do, or that they did not know how to further improve efficiency on their farms. A small number of respondents (3%) claimed that financial constraints prevented them from doing anything further to improve efficiency, while 4.2% of farmers declined to answer.

Table 4.6. Farmers' responses to 'Is there anything more you could do to increase efficiency on your farms?'

Answer	**Proportion of farms (%)**
Yes / Probably	41
No / Not a lot / Don't think so / Already doing everything we can	18
Invest in buildings and expansion	7
Don't know / Possibly	5
Improve efficiency of grass, fertiliser and slurry use	5
Financial constraints / If I had a grant	3
We're always looking for ways to improve	3
Get equipment for handling and monitoring, especially Electronic ID	3
Renewable energy	3
Farmland or soil improvement	3
Recycling rainwater	2
Reduce electricity bill	1
Variable speed drive	1
Reduce dairy unit workload	1
Work even longer hours	1
Unanswered	4

Respondents (93%) commented that the Welsh Government could help them increase efficiency further, and three quarters of these (72% of farmers) provided examples of things that could be improved to increase efficiency on their farms (Table 4.7). Specific examples for government-facilitated improvements suggested by farmers most frequently related to providing additional financial support, and economic regulation. Only 7% of farmers were unsure whether the Welsh Government could help them further to increase efficiency on their farms, or thought that nothing more could be done by the government.

Table 4.7. Farmers' responses to whether Welsh Government could help them increase efficiency on their farms.

Response type	Proportion of farms (%)
Yes	21
No	6
'More grants' (often 'More GES grants')	15
Less bureaucracy or paperwork	8
Buildings, fencing, and walls	8
Electricity (and 'Green energy')	6
Don't know / Possibly	5
Pay the GES grants we've been waiting for	5
Equipment funding (e.g. Electronic ID)	5
Soil investment	3
Increase fertiliser and slurry efficiency (e.g. with a GPS grant)	3
'Get a better agricultural minister than Carwyn Jones'	2
Farming Connect is beneficial	2
Clear TB	2
Cattle keeping and comfort	2
Support farmers under 40	2
Keep the price of beef and lamb up	2
'We like to think the government respects that farming is among the most important industries Wales has to offer'	1
Capital items	1
Send more advisors out	1
Benchmarking	1
Not reduce Single Farm Payment as much / Use Euros	1
Give equal playing field against English farmers	1
Unanswered	1

4.4.6 Awareness of 'sustainable intensification'

More than half of respondents (55%) either did not know the meaning, or had never heard of, the term 'sustainable intensification' (Table 4.8). Of the remaining 45% of respondents, 42% offered a definition, but only 8% provided an accurate definition.

Table 4.8. Farmers' responses to the question 'Have you come across the term 'sustainable intensification' and if so what would it mean for you farm?'

Response	Proportion of farms (%)
Haven't heard of it	44
Don't know the meaning	11
An increase in intensity without harming the environment	8
An increase in efficiency / productivity	8
'A good thing'	7
'What they're trying to do with Glastir'	6
An increase in sustainability / environmental friendliness	4
For organic farms, it involves increasing farm efficiency while decreasing input	2
It would mean increasing profits	2
An increase in long-term viability for the whole of Wales	1
Optimum cropping / livestock numbers	1
'It means focusing investment on infrastructure instead of on efficiency'	1
'It would mean more livestock kept per hectare, and more work for the current area we farm; returns need to be better to pay for employees to cover the extra work'	1
'We're not very intensive anyway'	1
'Not plausible for organic farms'	1
Unanswered	4

5 DISCUSSION

5.1 Survey design

5.1.1 Sampling design

A number of caveats need to be considered before discussing the findings of the study. Both the total number of respondents, and the spread of respondents across sub-categories of farm type and size, can influence the representativeness of conclusions drawn from the resulting survey data. This socio-economic survey yielded a relatively large sample size, with 120 of the 157 (76%) farms completing the survey. Additionally, the number of surveys completed within each farm type and size category was approximately proportionate to the number of GES participants in each category. Therefore, it can be assumed that the opinions of farmers taking part in this study are representative of all farmers participating in the Glastir Efficiency Scheme.

5.1.1.2 Dissemination method

The survey data was collected through the combined use of telephone interviews and anonymous postal surveys. It is important to bear in mind that the data gathering technique can introduce potential bias into a study, such as social desirability bias and/or non-response bias (Warner 1965; Fisher 1993; Ansolabehere & Schaffner 2014).

Social desirability bias, also known as the *good subject effect* (Nichols & Maner 2008), arises when respondents wish to present a favourable image of themselves through their responses to questions, independent of the underlying validity of their responses (Furnham 1986). Such a bias tends to be more marked in face-to-face interviews where the desire to please the interviewer is at its strongest. This leads to the over-reporting of desirable behaviours and the under-reporting of undesirable items (Bowling 2005). Telephone interviews tend to minimise this effect, but the extent to which it influenced this study is difficult to determine.

By contrast, postal surveys are susceptible to non-response bias. The reliability of the survey can be undermined if the response rate becomes too low. A typically acute risk is that the non-responders may differ in some marked way from the responders. Such sample bias can invalidate attempts at population estimates (in this case, the opinions of all GES-participating farmers; (Bowling 1997; Lahaut *et al.* 2002)). All surveys that typically seek to elicit responses using data collection techniques employing postal, telephone, computer or face-to-face data collection methods are likely to suffer from non-response bias (Hill *et al.* 1997; Lahaut *et al.* 2002; Bowling 2005). Surveys that ask sensitive questions are likely to compound lower response rates as they will be further affected by social desirability bias (Tourangeau, Rips & Rasinski 2000). However, given the high response rate of this study, non-response bias is likely to be negligible.

5.1.2 Grant implementation status

Not every farm participating in the Glastir Efficiency Scheme had implemented the capital works funded by GES grants by the time the survey was conducted. This may be for a number of reasons, such as capital works being postponed due to delays in receiving grant money, or because of seasonal constraints to construction projects.

Implementation of many types of grants may have be constrained by seasonal conditions, for example, instalment of outdoor works such as slurry or manure stores would require suitable weather conditions in order to begin construction. Given that local weather conditions vary across Wales, this may have contributed to individual farms finishing projects at different times.

The relative progress of GES funded works on individual farms indicates that respondents would have experienced differing levels of benefits (or dis-benefits) from GES capital works, thereby influencing their survey responses. For example, building new slurry and manure stores would be expected to increase storage capacity for livestock manures. Approximately 40% of dairy slurry is usually applied in February-April, while only 10% is typically applied in May-July, and 25% each in August-October and November-January (Smith *et al.* 2001). Farmers completing the survey after the main period of application would have more evidence relating to the impact of GES-funded works, than those who completed it before this period. Since 78% of respondents completed the survey in July 2014 (after the main slurry application period), the data received regarding this particular grant type (SME grants) are probably more robust. This may not be the case with data relating to other grant works, particularly those that had not had time to take effect by the time the survey was completed.

5.2 Socio-economic impact of GES grants

5.2.1 Impact on Labour

The impact of the GES on labour and farm workload varied between worker categories and farm characteristics. With the provision of grants for on-farm development, a net increase in annual workload might be expected, to incorporate the additional hours required to implement construction works. An average net increase of 3.3 labour-days per farm per year was indicated when all farm and worker categories were considered together (Fig. 4.10), although this average conceals important differences in workload changes, worker categories, and the influence of farm types and sizes.

Farm type affected changes in workload, by a greater margin for some farm types than others. Most notably, an average increase in annual labour-days was seen on LFA cattle and sheep farms (3.3 labour-days per farm per year for contractors and 0.8 days per farm per year for new employees), but a large decrease was observed on lowland dairy farms (10.7 days per farm per year for existing employees and 4.3 days per farm per year for contractors). In terms of farm size, contrasts were seen between farms < 50 ha in size (no overall change), 50 to 199.9 ha in size (an overall increase), and > 200 ha in size (an overall decrease). It is important to consider the response in workload of different farm types and sizes when allocating future grant funding, and when considering the up-scaled effect on the Welsh economy as a whole.

5.2.2 Allocation of spending

Most farmers agreed that GES grants had a positive impact for capital investment and motivating project development. More than 90% of farms either agreed or strongly agreed that the grant encouraged new capital investment (Fig. 4.7). Additionally, 82% of respondents said that their project would not have happened without the grant (Fig. 4.8).

Clearly, GES grants are not intended to curtail opportunities for expansion, but in some cases, development in one area may limit development in another. However, over 70% disagreed that the grants curtailed expansion, with only 15% agreeing that it had done so.

Three out of four respondents reported a positive impact on reducing fertiliser consumption and labour costs, after receiving GES funding (Fig. 4.9). Forty-six respondents gave monetary figures for how much their farms had saved on fertilisers (an average of £3,291 per farm). This suggests that the GES has helped improve farm input costs, as well as providing additional benefits, such as reducing on-farm greenhouse gas emissions (GHG) associated with fertiliser use, and potentially wider reductions in GHG emissions associated with fertiliser production.

5.2.3 Impacts on the wider economy

Overall, 77% of respondents reported that GES grants appeared to have had a positive impact on farm viability. The majority of respondents' GES grant expenditure (68%) was allocated to Welsh industries, with a large portion of the remainder going to Welsh households (18%). This suggests that the majority of grant money is entering the local economy, although to a slightly lesser extent than that under the Tir Gofal scheme, where 73% of expenditure was directed towards Welsh industries, and 23% towards Welsh households (CEASC 2005). Imports and taxes in the present study account for approximately 8% of the increased expenditure – more than twice the proportion spent on taxes and imports under Tir Gofal (CEASC 2005). The majority of imports were sourced from the UK (57%), and all imported products were sourced from within the EU (section 4.4.4.3).

Most of the expenditure allocated to imports was spent on either building materials (87% of responding farmers) or machinery and equipment (65%; section 4.4.4.3). Less than half of the 60 farmers spent money on labour, suggesting that many farmers preferred to manage labour requirements themselves. This may explain the pronounced difference observed between the reduction in labour-days worked on smaller farms (50 to 199.9 ha in size), and the increase in labour-days worked on larger farms (> 200 ha in size) – larger may have been able to afford to subcontract work, or may have had a greater need for additional labour corresponding to larger construction projects.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study set out to generate information on the impact GES grants have had on four key themes: grant allocation, economic outputs and farm efficiency, labour and the wider economy). Each of these are taken in turn in this conclusions section.

6.1.1 Grant allocation

The results highlight an information gap regarding the number of approved grants and grants in progress. This aside, the report has observed that the number of grants have been dispersed equitably across farm types and size categories. Farmers opted primarily to improve slurry and manure efficiency and energy efficiency.

6.1.2 Economic outputs and efficiency of farms

The Glastir Efficiency Scheme had positive impacts for farm economy indicators, such as increased farm sales and the value of those sales; wider? expenditure, and increased uptake in new capital investments.

6.1.3 Labour

The impacts on labour were varied across farm types and size. The previous scheme, Tir Gofal, increased demand for labour. For GES, some farms have had an increased demand for labour and others a reduced demand, but overall there was a net decrease.

6.1.4 The wider economy

The GES grants increased perceived farm viability and had a positive effect on farm expenditure, e.g. less money spent on fertilisers. Increased grant expenditure was spent locally on Welsh industries and households. The majority of imports came from the UK and Ireland and no imports were sourced from outside of Europe. Evidently, much of the money from GES grants is being recirculated within the local economy. In rural areas this is particularly important.

6.2 RECOMMENDATIONS

6.2.1 Grants

There were no water efficiency grants in progress according to the progress report (WG 2013). The number of these grant types was considerably lower than for SME and EE, and it may be useful to further understand the drivers for this lack of uptake for WE grants. There were very few farms of <50 ha within the GES. There may be the potential for policy makers to consider developing grants suitable for smaller sized farms.

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ACKNOWLEDGEMENTS

This research was made possible through WG funding via the GMEP project, and the kind participation of the farming community.

Annex 1

Glastir Efficiency Scheme social-economic survey

The Glastir Efficiency Scheme, previously known as ACRES, aims to increase the efficiency of Welsh farms by granting funds towards capital investments in slurry, manure and water storage and management as well as in energy efficiency.

The following questionnaire is aimed at assessing **only the Glastir Efficiency Scheme** and its impact on the Welsh economy (and not the other schemes within Glastir).

I. Economic outputs and efficiency

1. How has the value of your sales from your farming enterprise changed since obtaining a Glastir Efficiency Scheme (ACRES) grant?

- Increased
- Stayed the same
- Decreased
- Don't know

2. What impact do you think that the Glastir Efficiency Scheme (ACRES) grant has had on your sales from farming?

- Important positive impact
- Little positive impact
- No impact
- Negative impact
- Important negative impact

3. Your opportunities for expansion have been curtailed as a result of your Glastir Efficiency Scheme (ACRES) grant.

- Strongly agree
- Agree
- Don't know
- Disagree
- Strongly disagree

II. Allocation of spending

4. Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to undertake new capital investment.

- ○ Strongly agree
- ○ Agree
- ○ Don't know
- ○ Disagree
- ○ Strongly disagree

5. Access to the Glastir Efficiency Scheme (ACRES) grants encouraged you to increase the scale of planned investments.

- ○ Strongly agree
- ○ Agree
- ○ Don't know
- ○ Disagree
- ○ Strongly disagree

6. How much do you agree or disagree with the following statements?

MY FUNDED PROJECT WOULD	STRONGLY AGREE	AGREE	NEITHER AGREE NOR DISAGREE	DISAGREE	STRONGLY DISAGREE
NOT HAVE HAPPENED WITHOUT THE GRANT	○	○	○	○	○
HAVE HAPPENED MORE SLOWLY WITHOUT THE GRANT	○	○	○	○	○
HAVE BEEN SMALLER WITHOUT THE GRANT	○	○	○	○	○

7. Within changes in expenditure due to Glastir Efficiency Grant (ACRES) Scheme, what were the impacts on the following sectors?

	POSITIVE IMPACT	NEGATIVE IMPACT	NO IMPACT
FERTILISERS	◯	◯	◯
CHEMICALS	◯	◯	◯
ON-FARM PURCHASES (FEEDSTUFF, FUEL)	◯	◯	◯
VETERINARY FEES	◯	◯	◯
CONTRACTORS	◯	◯	◯
BUILDING MATERIALS	◯	◯	◯
LABOUR	◯	◯	◯

8. By how much were your fertiliser expenses reduced due to the Glastir Efficiency Grant (ACRES) Scheme?

=£

9. By how much were your chemical expenses reduced thanks to the Glastir Efficiency Grant (ACRES) Scheme?

=£

10. By how much were your on-farm purchases expenses reduced thanks to the Glastir Efficiency Grant (ACRES) Scheme?

=£

III. Impacts on labour

11. By how many days of labour per year was the workload on your farm **reduced** as a result of your Glastir Efficiency Grant (ACRES)?

Number of days =

12. Or, by how many days of labour per year was the workload on your farm **increased** as a result of your Glastir Efficiency Grant (ACRES)?

Number of days =

13. (*if answered to Q.11 or Q.12)* What proportion of the increased workload was devoted to the following labour sources on an annual basis :

	Proportion of reduced workload	Proportion of increased workload
Farmer		
Family		
Existing employees		
New employees		
Contractors		

Please provide answers to the following three questions (14, 15 and 16) in the table provided below.

14. How many of each of these types of people work on your farm nowadays?

15. How many hours do the workers work per week nowadays? Please differentiate hours worked and hours paid.

16. How many hours do you think they would work per week nowadays if you had not received grants from the Glastir Efficiency Grant (ACRES) Scheme?

Please place a tick in the appropriate column for each of the following

Worker type	Number	Hours worked per week	Hours paid per week	Hours per week without Glastir grant
Full-time male family workers				
Full-time female family workers				
Part-time male family workers				
Part-time female family workers				
Seasonal male family workers				
Seasonal female family workers				
Full-time male employees				
Full-time female employees				
Part-time male employees				
Part-time female employees				
Seasonal male employees				
Seasonal female employees				

part time workers = 30 hours a week.

IV. Impacts on wider economy

17. Has the grant from the Glastir Efficiency Scheme (ACRES) changed the viability of your farm enterprise?

- Increased
- Stayed the same
- Decreased
- Don’t know

18. What impact did the Glastir Efficiency Grant (ACRES) scheme have on any changes in expenditure?

- Strongly positive
- Positive
- No impact
- Negative
- Strongly negative

19. The overall annual farm expenditure has **increased** following the investment under the Glastir Efficiency Grant (ACRES) scheme.

- Strongly agree
- Agree
- Don't know
- Disagree
- Strongly disagree

20. OR **decreased** following the investment.

- Strongly agree
- Agree
- Don't know
- Disagree
- Strongly disagree

21. *(If expenditure increased)* Out of the increased spending as a result of the Glastir Efficiency Scheme grant (ACRES), what proportion was allocated to the following (answer to the best of your knowledge):

	Proportion of grant
Welsh industries (materials, machinery,…)	
Welsh households (labour, farm income,…)	
Taxes + imports	

22. If unable to answer Q19, please name purchased products and their manufacturers.

23. What proportion of the Glastir Efficiency Scheme's grants was allocated to the following sectors:

	Proportion of grant
Building materials	
Machinery/equipment	
Rental and hire	
Repairs	
Labour	

24. What proportion of the expenditure was allocated to taxes?

25. What proportion of the expenditure was allocated to wholesalers who import products from outside Wales?

26. Of the expenditure allocated to imports, for what purposes/sectors/products was the spending allocated?

27. Of the expenditure allocated to imports, towards which countries was the spending allocated?

28. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your suppliers?

- o Beneficial effect
- o no effect negative effect
- o Don’t know.

29. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your customers/clients/suppliers?

- o Beneficial effect
- o no effect
- o negative effect
- o Don’t know.

30. What has been the financial effect of the Glastir Efficiency Grant (ACRES) scheme on your competitors?

- o Beneficial effect
- o no effect
- o negative effect
- o Don’t know.

31. Is there anything more you could do to increase efficiency on your farm?

32. Is there anything more Welsh Government could do to help you increase efficiency on your farm?

33. Have you come across the term “sustainable intensification” and if so what would it mean for your farm?

Many thanks for the time and effort you have put into the completion of this survey. The information you provide is critical to our understanding and improving the scheme’s objectives.

Appendix 5.1: Measuring the impact of Tir Cynnal and Tir Gofal on bird populations in Wales

Daria Dadam and Gavin Siriwardena
British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2PU, UK.

Introduction

Tir Gofal (TG) was the first widespread all-Wales Agri-Environment Scheme (AES) from its inception in 1999 until 2013, with over 300 farms taking part in the scheme (Medcalf *et al*. 2012). It developed from its predecessor schemes, Tir Cymen and the Welsh component of the UK Environmentally Sensitive Areas scheme, which were restricted to limited areas of Wales. TG, a competitive entry scheme, was a "deep and narrow" AES (analogous to the Higher Level element of the Environmental Stewardship scheme in England), whilst Tir Cynnal (TC), its "broad and shallow" counterpart, was introduced in 2005. TG aimed at encouraging agricultural practices that could enhance Welsh landscapes, cultural features and wildlife, and it targeted whole farms, while the main objective of TC was to protect habitats in Wales (Medcalf *et al*. 2012).

Birds are a specific target of a considerable proportion of the management options in TG and TC, they are among the aspects of the environment and nature that are valued most highly by people and are well-represented in national-scale monitoring data that facilitate investigations of management effects at the landscape scale. Therefore, responses of bird populations to management provide a good approach for the assessment of AES performance.

Previous research has investigated the effect of Environmental Stewardship (ES) in England (Davey et al. 2010, Baker *et al* 2012, Siriwardena *et al* 2014) while the potential effectiveness of TG has been considered through a literature review investigating whether the scheme could deliver the requirements of a limited number of bird species (Morris *et al* 2010). Results of the latter suggested that TG had moderate to good potential to deliver benefits to most species considered (Black Grouse *Tetrao tetrix*, Grey Partridge *Perdix perdix*, Lapwing *Vanellus vanellus*, Curlew *Numenius arquata*, Chough *Pyrrhocorax pyrrhocorax*, Tree Sparrow *Passer montanus* and Yellowhammer *Emberiza citrinella*), as the range of option prescriptions provided most of their ecological requirements (Morris *et al* 2010). A second study considered the effect of TG on Yellowhammer, Curlew and Lapwing at farm and field level over up to two years, comparing TG farms that had chosen options with the potential to benefit target species with non-scheme farms (MacDonald *et al* 2012). The authors found that Yellowhammer populations during the breeding season were higher on TG farms, but there was no evidence that Curlew and Lapwing were more abundant on land included in TG (MacDonald *et al* 2012). The same study found that suitable land in TG did not hold more lekking Black Grouse than non-TG land, and that Chough nest site productivity did not vary with the prevalence of TG within 300 metres of the nest, although a negative effect had been expected from the decreased grazing regime that many TG grassland options entail (MacDonald *et al* 2012). However, the latter study considered only habitat associations and, to date, no research has been conducted to assess whether the implementation of TG and TC schemes has benefited bird population growth.

The principal environmental threats to birds in Wales and causes of the declines that have occurred are associated with changes in agricultural practices, such as specialisation and intensification, but also with abandonment of agricultural land in some areas (Chamberlain *et al* 2000, MacDonald *et al* 2012) and the changes in upland regions to some management practices such as grazing (e.g. Bonn *et al* 2009). The TG and TC schemes therefore were designed to provide or to maintain suitable habitats for key target species in Wales, such as Black Grouse, Chough, Curlew, Grey Partridge, Lapwing, Tree Sparrow, Corn Bunting (*Emberiza calandra*) and Turtle Dove (*Streptopelia turtur*), although the last two species were rare at the inceptions of the schemes and have almost entirely disappeared from Wales in recent years (Balmer *et al* 2013).

In this study, we apply the analytical approach used by Baker et al. (2012) to survey data for birds in Wales and the available spatially explicit information on the uptake of each scheme and the options within them, with the aim of assessing the effects of management over the entire course of each scheme on bird population growth rates. The bird data are drawn from the BTO/JNCC/RSPB Breeding Bird Survey (BBS), a national, volunteer-based scheme, for 1999 to 2013 for TG and 2003 to 2013 for TC, allowing population levels before the start of each scheme to be considered.

Methods

BIRD SURVEY DATA

BBS is an annual (1994-present), UK-wide, volunteer-based survey of randomly located 1km squares and it covers c. 260 randomly selected 1km squares in Wales annually. Volunteers walk two nominally parallel 1km transects (500m apart) through each square twice during the breeding season. Each transect is divided into five 200m sections; species-specific bird counts and habitat are recorded separately in each. Annual, square-specific counts are calculated as the maximum over the two visits of the total count summed across transect sections (Harris *et al.* 2014). For this study, BBS squares were selected if they were within Wales and had been surveyed in ≥2 years between 1999 and 2013 (excluding 2001 because the survey coverage was reduced due to access restrictions introduced in response to an outbreak of Foot & Mouth Disease).

Bird species for consideration in the analyses were selected according to the potential benefits they could gain from each option group, i.e. from the habitat created from TG and TC, and subject to their being recorded in sufficient survey squares to make analyses tractable. Note that several species that would ideally have been considered could not be tested in some or all habitats, because a minimum sample size of 30 squares, a standard threshold for BBS analyses, was not reached. The only exception was Lapwing (*Vanellus vanellus*) which was retained in the analysis because of the specific interest in the species as indicated by the provision of a Lapwing-specific set of options (Table 2). Species that could not be included in the analyses, for both TG and TC, were: Barn Owl (*Tyto alba)*, Buzzard (*Buteo buteo*), Chough (*Pyrrhocorax pyrrhocorax*), Corn Bunting (*Emberiza calandra*), Dunlin (*Calidris alpina*), Dartford Warbler (*Sylvia undata*), Golden Plover (*Pluvialis apricaria*), Great-Spotted Woodpecker (*Dendrocopos major*), Hen Harrier (*Circus cyaneus*), Marsh Harrier (*Circus aeruginosus*), Marsh Tit (*Poecile palustris*), Merlin (*Falco columbarius*), Oystercatcher (*Haematopus ostralegus*), Grey Partridge (*Perdix perdix*), Kestrel (*Falco tinnunculus*), Red grouse(*Lagopus lagopus*), Redshank (*Tringa totanus*), Ring Ouzel (*Turdus torquatus*), Short-eared Owl (*Asio flammeus*), Snipe (*Gallinago gallinago*), Sparrowhawk (*Accipiter nisus*), Tree Pipit (*Anthus trivialis*), Tree Sparrow (*Passer montanus*), Wheatear (*Oenanthe oenanthe*), Whinchat (*Saxicola rubetra*), Willow Tit (*Poecile montana*), Wood Warbler (*Phylloscopus sibilatrix*) and Yellow Wagtail (*Motacilla flava*). For TC alone, data for Curlew (*Numenius arquata*), Grey Wagtail (*Motacilla cinerea*) and Pied Flycatcher (*Ficedula hypoleuca*) were also insufficient. This means that the effects of management on these species can, at most, only be inferred from those on more common, related or ecologically similar species, if these exist.

AGRI-ENVIRONMENT DATA

The AES considered here were TG and TC, which comprised agreements between land owners/managers and the government in Wales. The schemes required the implementation of particular options, chosen by farmers from specific menus available (Annex 2) and outlined in the relevant handbooks (Tir Gofal Management Plan and Tir Cynnal Scheme Rules, each as supplied to farmers by the Welsh Assembly Government), or the protection or creation of valuable habitats, for a minimum of ten and five years, respectively. Data from the entire history of each scheme were considered. The spatial boundaries and start/end dates of all agreements in both schemes were available, so informed the overlap between 1km BBS survey squares (see below) and the management that was in place in each year. The number of squares within each Scheme and for each year is listed in Table 1. TG agreement data consisted of option-specific quantities of management for each agreement whilst, for TC, only agreement boundaries were available. TC involved the protection of 5% of the agreement area as "wildlife habitat", or the creation of such habitat if sufficient area was not already present. The habitat types that qualified as "wildlife habitat" for protection and the options available for habitat creation are listed in Table 2. Data on the types of habitat created or protected under TC in practice were not available, so analyses could only be conducted using amounts of overlap between agreement boundaries and survey squares, without considering agreement content. To refine this coarse measure, because the habitat potentially protected or created will have varied with land-use, the overlap areas were divided into arable, grassland and woodland, using the Land Cover Map 2000 provided by the Centre for Ecology and Hydrology. Thus, TC management was assessed in terms of the area under management, allowing for different influences of the restoration, enhancement or protection of different gross land-use types. Clearly, it would have been preferable to consider the real areas of management or habitat protection but, in the absence of this information, the approach taken acknowledges that different actions will have been taken in different habitats (Tir Cynnal Scheme Rules by the Welsh Assembly Government), so producing an analysis as close to management-specific as was possible and accounting for the likelihood that the types of management employed and their effectiveness will have varied with landscape. It is important to interpret the results with caution, however, because the precise management undertaken was unknown, making the details of cause and effect impossible to determine.

Spatial data containing agreement details for each holding (supplied by the Welsh Government) were used to quantify quantities of each option, for TG, or areas of gross habitat under agreement, for TC, present in each BBS square per year (Fig 1), and taking into account agreement start and end dates. All spatial analyses were undertaken using ArcMap 9.2 (ESRI 2010). Agreement boundaries were available in digital format, but the precise locations of individual management options within each TG agreement, and therefore within each 1km survey square, were unknown. Consequently, the amount of each TG option per agreement and square was estimated by assuming that the quantity of each option falling within each square was proportional to that of the whole agreement area in the square. TG options were grouped into categories (Table 3 and 4), based on the nature of the management and its expected effects on birds, in order to maximize statistical power. It would also have been of interest to investigate particular individual options but sample sizes were insufficient. Option grouping has the potential to weaken apparent relationships, if options with stronger effects are combined with those with weaker ones, but in reality this should trade off against sample sizes in terms of statistical power. TG also includes a number of options (e.g. heather burning or cutting, scrub clearance and invasive species control) that tend to support refinement of the basic option management or specific means of achieving the management goal, but are recorded simply as a duplication of the quantity of the basic option, so there is no straightforward way of quantifying their potential impact additively in combination with that of the basic option. Quantities of these options were therefore not included in the analyses to avoid undue inflation of apparent management areas under AES.

The above data processing produced total, annual quantities of management in each option category or amount of habitat within agreement for each survey square. These data then formed the predictor variables, separately for TG and TC (Table 3 and Table 4), used in the analyses described below. Management options are expected to influence population growth primarily via effects on demography, so option quantities were matched with square-specific bird counts after a one-year time lag, i.e. management needed to be in place for the breeding season before a focal year in which birds were counted.

Tests on TG data were conducted for options aimed at broad-leaved woodland, scrub, heath, unimproved grassland, wet grassland, arable land (options aimed at leaving weeds, unsprayed root crops followed by winter grazing, stubble, field margins, wildlife cover crops), and options to benefit Lapwings, grouped in option categories (Table 3) according to their targeted result in respect of habitat change. Management targeted at any given background habitat would be expected to be more common, by chance, where that habitat is more common. Hence, areas of relevant background habitat were controlled in each analysis. TC implementation was tested on areas of the following Land Cover categories that overlapped TC agreements: acid grassland, calcareous grassland, improved grassland, rough grassland, arable habitat, broadleaved woodland and heather (Table 3). Clearly, such areas may well be correlated with areas of TG uptake, so it was important also to control for TG in order to isolate, as far as possible, any effects of TC. Along, again, with the area of relevant background habitat in a focal square, the area under TG in the same background habitat was, therefore, calculated and included in the analyses as a control.
For each of these option groups, both the nominal target species for each form of management and all other species that might plausibly benefit were tested (Table 3).

STATISTICAL ANALYSIS
Analyses followed the approach for modelling variation in population growth rate with respect to environmental variables devised by Freeman & Newson (2008) and employed in an analogous analysis of agri-environment effects to that used for lowland farmland birds by Baker et al. (2012). Details of the model structures are presented in those two papers, so they are only summarized here. The method uses a log-linear approach that models the average change in expected abundance between consecutive years and can incorporate effects of spatio-temporal covariates, e.g. ES option quantities, on local growth rate. This approach allows maximum use of the available data by including observations from squares that had not been surveyed, or that had zero counts, in the previous year. Fundamentally, the analyses estimated the additional effect of management on each species' population growth rate but, importantly, growth is not thereby forced to be greatest in the years of highest management levels because annual variation in background population growth is allowed for. For each option, the models included a control for the area of the habitat in each survey square that might be confounded with the area of the option concerned. This was important because species associated with such habitats might well show more positive population trends where there is more of the habitat, while larger, habitat-specific AES management option areas would be expected by chance where there is more of the habitat concerned. Hence, spurious apparent relationships with AES management might occur if such controls are not used. The Land Cover Map controls used for each variable in the analysis are listed in Table 2. For example, for management options applicable to heather moorland, the area of heather moorland in the square (drawn from LCM2000, defined as the "Broad Habitat" named "dwarf shrub heath"), was used. Land Cover Map codes included in each habitat are illustrated in Table 5.

Models were fitted assuming a Poisson distribution for the observed BBS counts using the GENMOD procedure in SAS 9.2 (SAS Institute Inc. 2008), accounting for overdispersion using Pearson's χ^2 goodness-of-fit statistic. The significance of ES effects on population growth rates was then assessed using likelihood-ratio tests (SAS Institute Inc. 2008).
Models were run for all of the option categories and species listed in Table 2. Sample sizes varied by species because not all species were found in all survey squares in one or more years (see Results).

Results

Management of grassland

Results are shown in Table 6 for associations between population growth rate and the different forms of management of grassland under TG. There was contrasting evidence for the overall effect of grassland management options on population growth rates, with one positive significant species, Linnet (P<0.01), and one negative significant one, Skylark (P<0.01) (Table 6a). Both significant associations were related to conversion of grassland to less intensive management, whilst neither options for management of wet grassland nor specific grassland options for Lapwings led to significant population growth rates (Table 6b and 6c).
Testing for TC and controlling for TG also provided some support for an overall negative association between grassland options and population growth rates. Two of the three tests significant at P<0.05 were negative (in both cases involving Skylark, associated with acid and calcareous grass management), as were two near-significantly negative (P<0.1) results for Meadow Pipit and Starling for acid grassland options. There was only one positive, significant effect on population growth rate, for Meadow Pipit in relation to management of improved grassland (Table 7).

Management of arable land

Associations between population growth rate and management of arable land under TG are displayed in Table 8. There was evidence of a balance in favour of a positive overall effect across all species, with three species showing significant, positive effects of winter seed provision on population growth rate, Greenfinch, Yellowhammer and Stock Dove, the latter showing a strong association (P<0.001), with no negative effects (Table 8). Option groups to provide invertebrates showed a less clear overall outcome, with one positive significant population growth rate (Whitethroat), one negative association (House Sparrow) and one near-significant, positive result (P= 0.059 for Yellowhammer, Table 8).
House Sparrow showed a positive significant population growth rate in relation to arable land under TC when TG was controlled for, but no other test results were significant (Table 9).

Management of woodland

Results for associations between woodland management option groups and population growth rate of key species are presented in Table 10. Overall, there were more significant, or near-significant, positive population growth rates associated with woodland management (nine) than negative ones (two).

The option group with the most associated positive population growth rates was that considering minimization or exclusion of grazing, which showed six positive associations, of which four were significant and two almost significant (Table 10a). Three of the four significant relationships involved ground-feeding or understorey-nesting species, namely Blackbird, Robin and Wren, while Song Thrush, another ground-feeder, was near-significant (P=0.053; Table 10a). The other (near-) significant results involved Spotted Flycatcher and Blackcap (Table 10a).
The second option group category aimed at managing stock density in woodland (at higher levels than the previous category) produced a significant, positive association for just one species, Spotted Flycatcher, but no other result approached significance (Table 10b).
There was no indication of a clear direction of overall effect of options designed to encourage woodland establishment, with an equal number of positive and negative effects (two each: Table 10c). Blackcap and Chiffchaff both showed strong positive effects on growth rate of this form of management, while Robin and Blue Tit showed negative associations (Table 10c).
A contrasting overall result was achieved for TC, with one significant and one near significant negative association. Specifically, Wren showed a strong negative effect on population growth rate, whilst there was a near-significant (P<0.1) negative effect for Blackbird, each with respect to broad-leaved woodland management (Table 11).

Management of heathland
Associations between population growth rate and heather management under TG are summarized in Table 12. There was evidence for a positive effect of the management on Meadow Pipit, which showed a strong, significant, positive effect on population growth rate and Skylark, for which there was a near-significant, positive relationship ($P<0.1$), although Lapwing showed a near-significant, negative association ($P<0.1$). Results for Curlew and Stonechat were not significant. Heathland areas under TC were also associated with negative effects on both species tested, Meadow Pipit and Skylark, (Table 13), i.e. the opposite effects to those found for TG options alone.

Management of scrub
Results for population growth rate effects on key species of scrub management under TG are reported in Table 14. There was an indication of an overall positive effect of the management with two significant positive associations, Wren and Willow Warbler at $P<0.05$ and $P<0.01$ respectively, and one, Chiffchaff, reaching near significance ($P=0.068$). There was no management of scrub under TC.

Management of hedgerows
Associations between hedgerow management under TG and target species are reported in Table 15. There was an indication of an overall positive effect of this option on target species with five showing a significant positive population growth: Dunnock ($p<0.05$), Greenfinch ($p<0.01$), House Sparrow ($p<0.001$), Linnet ($p=0.01$) and Song Thrush ($p<0.01$). There was no management of hedgerows under TC.

Discussion
Across all species and option types tested, there was evidence of net positive effects of TG on the population growth rates of target species (20 significant and five near significant positive associations out of 24 significant and six near significant ones overall), but little support for the effectiveness of TC (two positive associations against five significant and three near-significant negative ones, over 10 significant or near significant population growth rates when TG was controlled for).

Management of grassland
Grassland occupies over half of the land-cover of Wales (Centre for Ecology and Hydrology 2007), so its management has the potential to be effective for wildlife proportionally. Intensification of grassland management has been associated with the decline of bird species through direct reduction in food availability for insectivores and seed-eating species as well as loss of heterogeneity and associated reduced access to prey items and nesting sites (e.g. Wilson et al 1999). Conversion or maintenance of grassland to less intensive management under TG, therefore, aimed at providing a more heterogeneous vegetation sward height, encouraging growth of native plants and increasing value for invertebrates, and results showed a positive effect on Linnet (Table 6). Research on ES in lowland England has also found a positive effect on population growth rate for grassland management in pastoral landscapes on Linnet (Baker *et al* 2012), probably showing a similar ecological response to the extensification of grassland management. However, there were no other positive effects across the six species tested and there was a surprising, negative association for Skylark with this type of grassland management (Table 6); the species requires taller vegetation in which to nest and lower vegetation where to forage, therefore it was predicted to benefit from this option group. Accordingly, Skylarks in lowland England were found to benefit from similar grassland management (Baker *et al* 2012), although more recent, analogous analyses have found less clear results: a non-significant relationship between the species and grassland management under ES in England (Siriwardena *et al* 2014).

The grassland area under TC showed a negative effect on population growth rate for the majority of species-grassland type associations, suggesting that TC was not adequate to address ecological requirements of the species and may have had unintended negative effects, and that any positive associations with AES were largely due to TG. An exception was Meadow Pipit, which showed a strong positive association with improved grassland areas overlapping with TC (Table 7). This could show a more heterogeneous sward providing the species with a preferred feeding habitat (Douglas et al 2008), but there was no evidence for such a benefit for Skylark or Starling. There was also a weak suggestion of a negative effect on population growth rate for Meadow Pipit and Starling on acid grassland under TC management, although the lack of detailed information on the TC option makes it difficult to interpret. Skylark showed a strong negative relationship with both acid and calcareous grassland under TC management. Again, this is difficult to interpret, but it may suggest that TC produced sward heights too tall for the species to forage in successfully.

Management of arable land

Management of arable land under TG provided mixed results. Arable land is rare in Wales, covering just over 3% of the land area (Centre for Ecology and Hydrology 2007), so samples of randomly selected squares are necessarily small and the power to detect effects of management in arable areas is correspondingly limited. The detection of significant relationships with TG in this study is therefore strongly suggestive of the existence of biologically important effects, even if the impact on national populations of some species is limited simply because there are few arable areas within which the species could have been affected.

Provision of winter seeds under TG through retention of stubble had a strong, significant, positive effect on population growth of Greenfinch, Stock Dove and Yellowhammer, but no significant effect on all other target species (Table 8). Previous research has shown that most granivorous farmland bird populations are limited by winter seed food availability and that reductions in this resource have driven the declines of species like Yellowhammer and prevented recoveries (e.g. Gillings et al 2005, Siriwardena et al 2007). The results here are consistent with recent work on ES in lowland England, which found analogous positive effects of winter stubble on population growth rates of Yellowhammer and Stock Dove, among numerous other species, albeit at a larger spatial scale for Stock Dove (Baker et al 2012). That more species, such as Dunnock, Skylark, Reed Bunting and House Sparrow did not show significant associations with seed provision may reflect the low power described above, a failure of the management to fill the critical resource gap (e.g. seed availability in late winter: Siriwardena et al. 2008) or different ecological or demographic pressures affecting Welsh birds as opposed to those elsewhere in the UK.

Management of arable land under TG for provision of invertebrates during the breeding season involved reduction of spraying of chemicals, creation of buffer areas between arable land and other features such as hedgerows and other wildlife habitats, and provide food plants and nectar sources for insects and other invertebrates . Increased use of pesticides in farmland has been linked to a decrease in invertebrates (e.g. Boatman et al. 2004, Chamberlain and Crick 1999), which support thrushes and warblers, for example, as well as being the principal food for chicks in the nest even of most granivorous species. While evidence is limited that breeding season food availability limits the abundance of farmland birds, it is possible that some species differ in ecology in different regions (e.g. Perkins et al 2011) and recent evidence suggests that breeding season AES management can have positive effects on species like Yellowhammer in an arable context (Siriwardena et al. 2014). The current study found a weak, positive effect on population growth rate for Yellowhammer (Table 8), suggesting an influence to add to that found for winter seed and similar to recent results for English AESs for this species (Siriwardena et al. 2014). There were no general, positive patterns, however, probably reflecting the general lack of importance of breeding season food as a limiting factor, the one exception being Whitethroat (Table 8). This migratory species nests in a wide range of field boundary habitats and invertebrate food availability is the most plausible limiting factor for abundance on the breeding grounds. As well as this positive pattern, however, there was a strong negative association with House Sparrow, which is difficult to explain. While the species might be expected to benefit from enhanced invertebrate food resources in some contexts, it is strongly associated with farm buildings and much of the relevant TG management is likely to have been located too far from nest sites to have been used. Thus, farms that featured this type of TG management may have tended to feature little positive management for sparrows closer to their nest sites and thus have been associated with declining populations.

Contrary to the TG result, House Sparrow was positively associated with arable land under TC. The broad purpose and approach behind this management were similar to those under the analogous TG options, but their effects appear to have differed. It could be that TC agreements, being simpler at the farm level, did not introduce the habitat biases that may have led to negative associations for House Sparrow with TG, as described above, but the lack of responses among the other species considered that have similar food requirements suggests that TC management failed to produce general habitat enhancements.

Management of woodland
Woodland (broadleaved, mixed and yew) covers 8.6% of Wales (Centre for Ecology and Hydrology 2007), but is probably disproportionately important in terms of biodiversity value as semi-natural habitat. Overall, there was evidence of a positive association between woodland management under TG and population growth rates of target bird species in this habitat, suggesting a significant area of success for the scheme.

Grazing of woodland understorey can lead to loss of suitable habitat for several species (Gill and Fuller 2007, Holt et al 2010); therefore, managing livestock grazing in woodland has the potential to benefit a number of species. In this study there was evidence of an overall positive association of restricting grazing pressure in woodland on species that nest or forage in the shrub layer, such as thrushes (Blackbird, Robin and Song Thrush) Wren and, to a lesser extent, Blackcap (Table 10a). Of particular interest was the population growth rate of Spotted Flycatcher, a fast-declining species (Baillie et al 2014), in relation to management that minimises or excludes grazing. The association was stronger in woodlands with some grazing (Table 10b), where it was the only significant species with respect to this management option, possibly because grazing opened up areas where the species can forage for flying insects, whilst retaining nest sites in denser vegetation. The parameter estimate for this species was, however, rather high, reflecting a small sample and suggesting that the result should be considered with caution.

Positive effects of woodland establishment were found for two species that favour open forest and scrub, although some other such species could not be tested. Blackcap and Chiffchaff showed strong positive effects on population growth rate with management aiming to establish woodland through plantation and reduced grazing (Table 10c), which should provide their preferred habitats, together with both food in the form of insects and nesting sites. The negative association of this management with Blue Tit and Robin may also reflect habitat requirements, because these species prefer denser vegetation structures and a more closed canopy or are found in hedgerows. New woodland or scrub may make habitat less favourable in the short term, or tend to have been associated with less favourable areas for these species because of landscape context, for example.

In contrast to TG, the associations between TC woodland management and population growth rates of target species tended to be negative, although only two patterns reached or approached significance (Table 11). This may reflect the focus of TC on habitat protection, as opposed to active management in TG, such that TC woodland may have been stable in quantity, but was still declining in quality, perhaps because of herbivore pressure, for example. However, while this could explain a lack of positive effects of TC woodland, it does not explain why protection under the scheme might have made the habitat worse for Wren and Blackbird.

Management of heathland

There were three significant or near-significant associations between heathland management under TG and population growth rates of the five species tested, of which the two positive ones involved non-heathland specialists, Meadow Pipit and Skylark. However, there was no evidence of an association with Curlew or Stonechat and a very weak negative association with Lapwing.
The strong positive association of Meadow Pipit with heather management may be due to the prescription to provide heather cover with some grasses and to restrict grazing, hence providing suitable habitat for the species, whereas this habitat would be less suitable for Lapwings. A previous study concluded that abundance of Meadow Pipit in upland regions was higher in landscapes which contained a mix of grass and heather than in those with only one type of vegetation (Vanhinsbergh and Chamberlain 2001). High levels of grazing have been considered generally detrimental in many upland regions in the UK (Evans *et al.* 2006) as they have been associated with loss of heather, mosaic vegetation structure and sward height (Anderson and Yalden 1981, Miles 1988, Nolan *et al*. 1995). TG management has probably therefore improved habitats for Meadow Pipits by enhancing the heather content of grass-dominated moorland. The failure to detect clear effects for the other species may partly be due to their relative rarity (Meadow Pipit is very common in upland heathland), but may also reflect weaknesses in the management, such as the generation of less than optimal vegetation structures for particular species.

Sample sizes permitted testing of TC effects in heathland for only Meadow Pipit and Skylark, but negative associations were found for both species (Table 13). As with woodland, this suggests that TC management failed to deliver the habitat enhancements for these species, perhaps because habitat protection, namely the prohibition of installing new drainage, extraction of peat and general disturbance (Welsh Assembly Government, Tyr Cynnal Scheme Rules), was insufficient to improve habitat quality. Again, however, this does not explain why TC might have had negative effects, which clearly suggests a significant conservation issue.

Management of scrub

Management of scrub under TG was positively associated with the population growth rates of two target species, Wren and Willow Warbler, with a further near-significant relationship with Chiffchaff (Table 14). All of these patterns are likely to reflect increases in vegetation density and diversity due to the management, improving both nesting cover (Ferguson-Lees et al 2011) and invertebrate food availability. There was no significant effect on seven species, however, suggesting either that the management was not effective for them or that their populations are limited by other resources.

Management of hedgerows

There was strong evidence, across species, for an overall positive association between hedgerow management under TG and population growth rates of target birds: five of the eleven species tested had significant, positive relationships (Table 15). Hedgerows provide nesting habitat for four of these species (Dunnock, Greenfinch, Linnet and Song Thrush; O' Connor and Shrubb 1986), while House Sparrows are likely to use this habitat to socialise, as they do in urban settings (Summers-Smith 1963). The House Sparrow pattern could, therefore, show a behavioural change as the birds become more detectable along BBS transects, but the other positive effects are more likely to reflect real population changes due to habitat improvement. Again, the non-significant results could reflect either management failing to deliver the precise habitat requirements of the species or limitation of abundance elsewhere, for example in open field habitats and/or in winter.

Conclusions

Baker et al. (2012) found a balance in favour of significant, positive effects of landscape-scale AES management in England, where the options concerned addressed the factors limiting target species' populations. The coverage of Wales by BBS is lower than that of England and the total sample size is smaller, so statistical power of the analyses conducted here is likely to have been lower. Moreover, many effects of AES management are likely to be small and potentially to be obscured by other environmental influences on populations, such as weather and conditions outside farmland. Hence, there are many reasons why positive effects of AES management, such as that under TG, might not be detected even if the management concerned is working locally. Conversely, when multiple statistical tests are conducted in a study like this one, a range of "significant" patterns are expected to occur by chance. However, such patterns should be evenly distributed between positive and negative associations, and the balance of effects across species and the ecological context help to inform about the reliability of apparent patterns. Overall, therefore, with the caveat that some rarer target species were not testable because of small sample sizes, the results of this study provide good evidence for broad, positive effects of several aspects of TG management, especially that concerning woodland, scrub, hedgerows and arable seed-rich habitats on target bird species. Other management under the scheme has not been so conspicuously successful.

While limited statistical power may explain some of the failure to detect positive effects of these other options, as well as for some species with respect to the option types listed above, it would be unwise to assume that sampling effects alone are responsible, or that negative or non-significant results for individual species do not reflect real patterns. First, positive effects will not occur if the management fails to address the factors limiting local or national abundance, or if the quality of the management is low and it fails to deliver the resources intended in sufficient quantities. This could be the result of problems with option design or option implementation. It is also possible that some TG options have had unintended negative effects on some species, for example by facilitating predation, competition or disease transmission (Bro et al. 2004, Siriwardena et al. 2014), that have over-ridden any positive impacts produced. There is no specific evidence that such effects have occurred in Wales, but they may be occurring in England (Siriwardena et al. 2014) and continued monitoring is essential to ensure that such issues are identified early and addressed in future AES schemes.

The results for TC in this study were much more equivocal than those for TG. This may reflect the intensity of management under the two schemes, because TG options required more tailored and more direct input from farmers, so would be expected to have greater impacts, *a priori*. It may also reflect the difference in age of the two schemes (TG being older), because management may take either some years to take effect (e.g. for grazing alleviation to influence woody vegetation structure) or require several years before positive effects are detectable statistically. However, it is important to recognize that the TC analyses here were weakened by the lack of direct data on the management undertaken or on the real changes effected in practice. Given the general lack of clear patterns across species, which would be expected among ecologically similar species if the management produced general changes in habitat quality (good or bad), it seems unlikely that the proxies employed in these analyses captured the variation in habitat management under the scheme effectively. As a result, it would be unwise to regard the results as definitive. If reliable historical data on TC uptake become available in the future, it would be valuable to repeat the analyses conducted here to derive stronger evidence as to the effectiveness of the scheme.

Overall, there is good evidence that TG has had positive effects on bird populations in Wales and, while many of those effects have been too small to reverse the declines of priority species, care may be needed to ensure that the gains that have been achieved are maintained and enhanced under Glastir. In practice, this means reviewing option design and improving it where necessary, as well as maximizing uptake, while also promoting the options that are most effective in terms of addressing the factors that limit the populations of target species. Further, the problems with the tests of TC here demonstrate that it is critical to collect accurate data about management to enable analyses of scheme effects. Nevertheless, the results of this study add further support to those from England in showing that national-scale AES management can produce positive population effects on target bird species.

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Figure 1. *Maps of the extent of all option coverage under Tir Gofal (a) and Tir Cynnal (b) and coverage of BBS squares in Wales (c).*

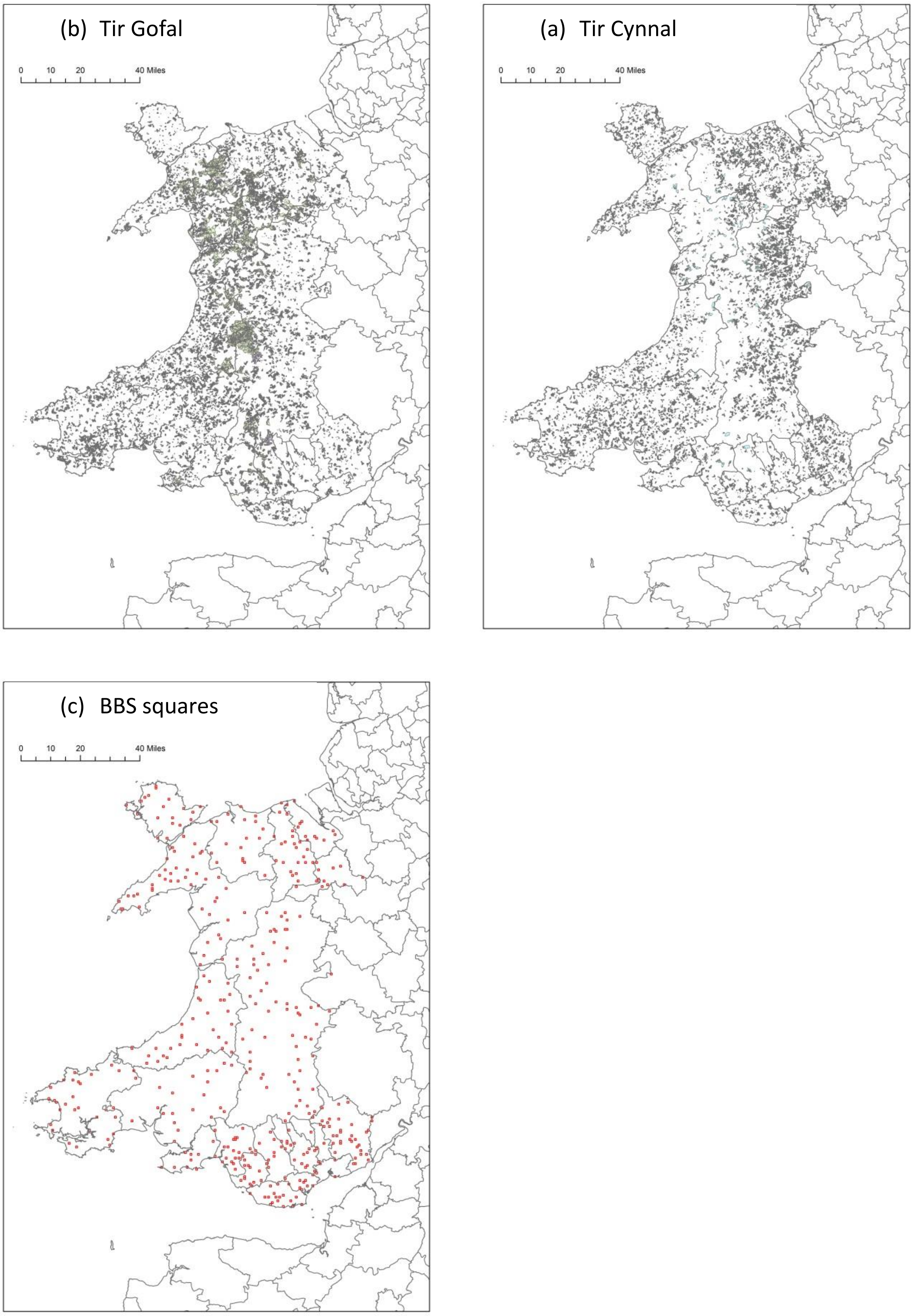

Table 1. *Sample sizes of all Welsh 1km survey squares divided between Tir Gofal and Tir Cynnal.*

Year	Number BBS squares - Tir Gofal	Number BBS squares - Tir Cynnal
1998	NA	NA
1999	NA	NA
2000	103	NA
2001	4	NA
2002	106	NA
2003	115	NA
2004	124	NA
2005	135	NA
2006	136	NA
2007	134	79
2008	113	90
2009	114	88
2010	111	93
2011	96	82
2012	135	99
2013	143	94

Table 2. *Tir Cynnal habitat creation option*

TC Habitat creation option	Description
Hedgerows	Provides a continuous strip of hedgerow at least 2 metre-wide, composed of native plants such as hazel, hawthorn, blackthorn and holly, which must be protected from livestock.
Streamside corridors	Creates a strip of at least 10 metre wide on average, protected from livestock.
Conversion of improved to semi-improved grassland	Creates semi-improved grassland that is not ploughed, and where use of inorganic fertilisers and herbicides are not permitted and wildlife habitat maintained.
Uncropped margins	Creates naturally-regenerated margins 4-12 metre wide free from molluscicides and farmyard manure and which is protected from livestock and vehicle usage.
Grass margins on cereal land	Provides a 4-12 metre wide strip of wildlife-enriching grasses which is cut or grazed once a year after middle of July and which is free from molluscicides and vehicle disturbance.
Small-scale broad-leaved tree planting	Creates a patch of native broad-leaved plants at least 3 metres apart and protected from livestock.
Wild-bird cover crop	Creates a field margins of at least 4 metre wide established by end of April and cut after mid-March of the following year containing at least two types of crop which are not sprayed by insecticides, fungicides, molluscicides or herbicides.
Unsprayed root crops	Establishes a root crop in the entire field or field margins before 1 July, which is free from insecticides, fungicides and herbicides and not grazed before mid-October or ploughed before 1 March of following year.

Table 3. *Option categories for (a) Tir Gofal and (b) Tir Cynnal with management description and list of species likely to benefit from them. Species in bold and underlined are those tested here whilst for the remaining there were insufficient data.*

(a) Tir Gofal	Description	Species likely to benefit	
Collective option name		Tested	Not-tested
Conversion/ maintenance to less intensive grassland	Creates and maintains heterogeneous sward height through reduced grazing pressure and limited application of fertilisers and herbicides.	CU, L., LI, MP, S., SG	BO, BZ, K., P., RK, SE, YW
Wet grassland	Provides marshy grassland through management of grassland species and water levels, and control of cutting and grazing pressure.	CU, L., MP, S., SG	RK, SN, MR, OC,
Lapwing-specific	Creates and maintains grazing marshes for Lapwings by managing grazing pressure to achieve a short vegetation sward and reducing grazing pressure between April and July. Water levels are also managed in winter and summer.	L.	
Rough-grass margins	Provides strips of rough grassland to entice small mammals as well as nesting and feeding sites for birds		BO., K., P.
Arable - Winter seed	Provides a supply of seeds during winter through stubble retention.	CH, D., GR, HS, LI, RB, SD, S., Y.	CB, K., TS
Arable - Invertebrates	Provides habitat for invertebrates through controlled use of herbicides and pesticides.	CH, D, HS, RB, S, SG, WH,Y.	P., TS , YW
Woodland- reduced stock grazing	Creates or maintains semi-natural broadleaved woodland with understorey, through limited grazing, and dead wood available.	B, BC, BT, CC, CH, GT, PF, R, RT, SF, ST, WO, WR, , WW	GS, MT, SH, WT
Woodland grazed by stock	Creates or maintains semi natural broadleaved woodland with grazed understorey and dead wood accompanied by sustainable timber extraction.	B, BC, BT, CC, CH, GT, PF, R, RT, SF, ST, WO, WR, WW	GS, MT, SH, WT,
Wood establishment	Provides an early succession of woodland tree species through retention of existing scattered trees, planting of species and grazing exclusion.	B., BC, BT, CC, CH, GT, R, ST, WR	G., SC, WH
Heathland	Creates or maintains upland heath by controlled grazing pressure and scrub management to encourage dwarf shrubs.	CU, MP, S., SC, L.	BK, DN, DW, HH, GP, ML, RG, RZ, SE, SN, WC
Scrub	Creates or maintains a structurally diverse scrubland with Bramble, Thorn, Gorse and Willow.	BC, CC, D., LI, R., SC, WH, WR, WW, Y.	TP, W., WC
Hedgerow	Preservation of hedgerows in fields	BF, CH, D., GO, GR, HS, LI, RB, SD, ST, WH	TS, Y.

(b) Tir Cynnal	Description	Species likely to benefit	
Collective option name		Tested	Not-tested
Acid grassland	Preserves the wildlife habitat intrinsic to this grassland type by not applying chemicals, limit vehicle disturbance and avoid exploitation of the soil.	MP., , S., SG	CU, L., RK.
Rough grassland	Preserves the wildlife habitat intrinsic to this grassland type by not applying chemicals, control grazing pressure, limit vehicle disturbance and avoid exploitation of the soil.	MP, S., SN	CU, L., RK
Calcareous grassland	Preserves the wildlife habitat intrinsic to this grassland type by not applying chemicals, avoiding overgrazing, limit vehicle disturbance and avoid exploitation of the soil.	MP, S., SG	CU, L., RK
Improved grassland	It may contain hedgerow management and conversion of improved to semi-improved grassland (see Table 4 for more details on this option).	CU, L., MP, S., SG	RK
Fen, marsh, swamp	Preserves the wildlife habitat intrinsic to this habitat by avoiding application of chemicals, limit grazing pressure, avoidance of installation of new drainage systems and clearance of ditches between 1 March and 31 August .	CU, L., RK., RW, SW, RB	
Dwarf, shrub, heath	Preserves the wildlife habitat typical heathland by avoiding overgrazing, limit vehicle disturbance and avoid exploitation of the soil including preventing peat extraction.	MP, S., SC,	BK, CU,DN, DW, HH, GP, L. , ML, RG, RK, RZ, SE, SN, WC
Broadleaved woodland	Should include small-scale broad-leaved tree planting (see Table 4 for more details on this option).	B, BC, BT, CC, CH, GT, R., RT, ST, WR, , WW	GS, MT, PF, SF, SH, WO, WT
Arable & horticultural	Likely to contain four Tir Cynnal habitat management options: wild-bird cover crop, unsprayed root crop, grass-margins on cereal land and uncropped margins (see Table 4 for more details on these options).	CH, D., HS, LI, S.	CB, K., P., RB, TS, Y.

Table 4. *Options category, group name, options codes, control variables, sample size, species list and area of option group breakdown for Tir Gofal and Tir Cynnal.*

Scheme	Option category	Grouping	Option codes	Landscape control variable	Number of survey squares with non-zero values	Mean of relevant options (ha)	Median of relevant options (ha)	Lower| upper quartiles of relevant options (ha)	
Tir Gofal	Grassland TG	Conversion/ maintenance to less intensive grassland	7A, 7B, 8, 8A, 8B, 9, 10, 10A, 10B, 32A1, 34A, 35A, 35B, 35C, 35D	General grassland	147	21.37	8.17	4.12	34.84
		Wet grassland	11,11A,42B, 36A, 36B, 36C1	No control	108	4.01	1.54	0.64	3.84
		Lapwing-specific	32B21,32B22,31D,34A,36C1,36A,36B	General grassland	7	1.85	0.86	0.54	1.92
	Arable fields TG	Winter seed	24B,25A,25B,27,29	Arable	44	4.92	2.16	0.87	5.56
		Invertebrates	24B,25A,25B,27,29, 30	Arable	42	4.58	2.67	0.93	5.56
	Woodland TG	Reduced stock grazing	1A, 1B	Broadleaved woodland	107	2.49	1.12	0.31	3.79
		Woodland grazed by stock	1C	Broadleaved woodland	63	0.81	0.48	0.23	1.06
	Heathland TG	Heathland	5, 6	Dwarf, shrub, heath	44	11.80	3.61	1.08	13.05
	Scrub TG	Scrub	2	No control	58	0.55	0.28	0.08	0.74
	Hedgerow	Hedgerow	18	Arable & horticultural +	108	633.39 metres	410.39 metres	144.55	1042.1

				calcareous grassland + improved grassland				metres	metres
Tir Cynnal	Acid grassland	Acid grassland	n/a	Acid grassland	38	6.35	2.15	0.37	7.12
	Calcareous grassland	Calcareous grassland	n/a	Calcareous grassland	52	1.80	1.08	0.51	2.11
	Improved grassland	Improved grassland	n/a	Improved grassland	127	10.11	6.25	1.09	12.88
	Woodland	Woodland (broad-leaved)	n/a	Woodland (broad-leaved)	91	2.31	0.78	0.20	2.37
	Arable & horticultural	Arable & horticultural	n/a	Arable & horticultural	60	3.23	1.07	0.12	3.61

Table 5. *Land Cover Map 2000 subclass habitat codes (Fuller et al 2002) included in each habitat category used as controls.*

Habitat	BH class		
	Codes	Names	Variants
Acid grassland	8	Acid grass and bracken	Acid, acid (rough), acid with Juncus, acid with *Nardus/Festuca/Molinia*
Neutral grassland	6	Neutral /semi-improved/rough grassland	Grass set-aside, rough grass (unmanaged), grass (neutral unimproved)
Calcareous grassland	7	Calcareous	Calcareous (managed), calcareous (rough)
Improved grassland	5	Improved grassland	intensive, grass (hay/ silage cut), grazing marsh
General grassland	n/a	Combination of acid, calcareous, neutral and rough, and improved grassland	n/a
Fen, marsh, swamp	11	Fen, marsh, swamp	swamp, fen/marsh, fen willow
Dwarf, shrub, heath	10	Dense dwarf shrub heath and open dwarf shrub heath	Dense or open ericaceous, gorse
Broadleaved woodland	1	Broad-leaved/mixed woodland	Deciduous, mixed, open birch, scrub
Arable & horticultural	4	Arable and horticultural	cereal, arable bare ground, root vegetables, horticulture, non-cereal , unknown, orchard, arable grass (ley), setaside

Table 6. *Population growth rate for grassland management options under Tir Gofal. Conversion to less intensive grassland management, management of wet grassland and management of grassland for Lapwing under Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant results (P<0.1) are underlined, n/a indicates insufficient data to run the analysis. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

		Conversion to less intensive grassland				Wet grassland				(c) Lapwing-management grassland			
Species	N	Est	SE	χ^2	P	Est	SE	χ^2	P	Est	SE	χ^2	P
CU	50	0.145	0.154	0.88	0.347	0.113	0.105	1.14	0.285	n/a	n/a	n/a	n/a
L.	20	-1.198	1.197	1.69	0.193	0.047	1.246	0.00	0.970	0.700	0.800	0.66	0.416
LI	120	0.472	0.162	9.29	**0.002**	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	119					-				n/a	n/a	n/a	n/a
MP		-0.043	0.076	0.32	0.571	0.011	0.031	0.13	0.717				
	133					-				n/a	n/a	n/a	n/a
S.		-0.297	0.055	31.55	**0.000**	0.048	0.044	1.21	0.271				
SG	104	-0.227	0.177	1.80	0.180	0.020	0.705	0.00	0.977	n/a	n/a	n/a	n/a

Table 7. *Population growth rate for management of grassland under Tir Cynnal controlled for Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels. Types of grassland where a species would not usually occur were not tested. I=Improved, A= Acid , C = Calcareous.* Statistically significant results are highlighted in bold, near-significant results (P<0.1) are underlined. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

			Grassland (habitat and Tir Gofal controlled)			
Species	N	Grassland type	Est	SE	χ^2	P
MP	56	I	0.131	0.148	828.63	**0.004**
S.	71	I	-0.212	0.112	10.46	0.746
SG	51	I	0.133	0.154	49.88	0.480
MP	56	A	-0.356	0.290	348.42	<u>0.062</u>
S.	71	A	-1.061	0.340	1983.44	**0.000**
SG	51	A	-1.436	1.296	286.31	<u>0.091</u>
MP	56	C	2.494	1.608	16.43	0.685
S.	71	C	-3.402	1.659	885.88	**0.003**
SG	51	C	-1.620	1.260	13.47	0.714

Table 8. *Population growth rate for arable land managed under Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant results (P<0.1) are underlined. W= winter food options, I= provision of invertebrates options; N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

Species	N	Arable management	Est	SE	χ^2	P
CH	259	W	-0.027	0.059	0.21	0.650
D.	204	W	0.060	0.075	0.65	0.420
GR	155	W	0.255	0.128	398.75	**0.045**
HS	167	W	-0.048	0.081	0.35	0.556
LI	120	W	0.244	0.156	2.42	0.120
RB	41	W	-1.422	1.506	0.87	0.351
S.	133	W	0.084	0.123	0.46	0.497
SD	43	W	0.895	0.186	28.19	**0.000**
Y.	42	W	0.249	0.120	4.39	**0.036**
CH	259	I	0.008	0.076	0.01	0.921
D.	204	I	-0.003	0.103	0.00	0.975
HS	167	I	-0.241	0.105	5.32	**0.021**
RB	41	I	-0.860	1.190	0.53	0.468
S.	133	I	0.098	0.124	0.63	0.428
SG	104	I	-0.460	0.324	2.18	0.140
WH	107	I	0.158	0.081	388.62	**0.048**
Y.	42	I	0.240	0.129	3.56	<u>0.059</u>

Table 9. *Population growth rate for management of arable land under Tir Cynnal controlled for Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant are highlighted in bold. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

		Arable (habitat and Tir Gofal controlled)			
Species	N	Est	SE	χ^2	P
CH	148	0.296	0.120	24.01	0.624
D.	104	0.090	1.555	252.00	0.112
HS	86	0.084	0.180	459.73	**0.032**
LI	66	1.560	0.179	9.47	0.758
S.	71	0.048	0.332	122.63	0.268

Table 10. *Population growth rate for woodland management: (a) options to minimise or exclude grazing, (b) managed grazing and (c) woodland establishment management under Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant are highlighted in bold, near-significant results are underlined, n/a indicates insufficient data to run the analysis. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

		Minimise/exclude stock grazing				Managed stock grazing				Woodland establishment			
Species	N	Est	SE	χ^2	P	Est	SE	χ^2	P	Est	SE	χ^2	P
B.	258	0.215	0.089	5.77	**0.016**	0.543	0.352	2.41	0.121	0.560	0.377	2.24	0.134
BC	181	0.259	0.137	3.54	<u>0.060</u>	0.698	0.506	2.00	0.157	1.776	0.574	10.76	**0.001**
BT	233	-0.036	0.103	0.12	0.727	-0.595	0.471	1.68	0.195	-0.829	0.364	5.20	**0.023**
CC	199	0.071	0.135	0.27	0.601	0.045	0.987	0.00	0.964	5.355	1.501	18.34	**0.000**
CH	259	0.069	0.100	0.48	0.488	0.117	0.256	0.21	0.650	0.380	0.311	1.51	0.220
GT	224	-0.091	0.126	0.52	0.472	0.761	0.476	2.67	0.102	0.197	0.471	0.18	0.675
PF	31	0.305	0.297	1.03	0.309	0.417	0.881	0.22	0.641	n/a	n/a	n/a	n/a
R.	252	0.200	0.095	4.43	**0.035**	-0.082	0.298	0.08	0.782	-0.967	0.319	9.37	**0.002**
RT	94	-0.029	0.194	0.02	0.879	-0.290	0.314	0.88	0.350	n/a	n/a	n/a	n/a
SF	33	1.237	0.539	5.53	**0.019**	11.637	4.281	7.95	**0.005**	n/a	n/a	n/a	n/a
ST	226	0.249	0.128	3.75	<u>0.053</u>	-0.093	0.504	0.03	0.853	-0.560	0.628	0.80	0.372
WO	29	-0.005	0.327	0.00	0.989	0.271	1.263	0.05	0.832	n/a	n/a	n/a	n/a
WR	255	0.465	0.086	28.36	**0.000**	-0.164	0.282	0.35	0.556	0.283	0.296	0.92	0.338
WW	191	-0.011	0.115	0.01	0.924	-0.049	0.257	0.04	0.850	n/a	n/a	n/a	n/a

Table 11. *Population growth rate for management of broad-leaved woodland under Tir Cynnal controlled for Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant ones (P<0.1) are underlined. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

		Broad-leaved woodland (habitat and Tir Gofal controlled)			
Species	N	Est	SE	χ^2	P
B.	132	-0.213	0.147	373.41	<u>0.053</u>
BC	93	0.390	0.275	17.34	0.677
BT	128	-0.428	0.183	4.01	0.841
CC	100	-0.250	0.250	42.04	0.517
CH	148	-0.264	0.177	93.44	0.334
GT	112	-0.631	0.230	36.38	0.546
R.	134	-0.427	0.166	38.11	0.537
RT	50	0.007	0.301	132.81	0.249
ST	114	-0.592	0.228	136.09	0.243
WR	135	-0.210	0.175	787.34	**0.005**
WW	101	-0.121	0.239	204.72	0.152

Table 12. *Population growth rate for heathland management under Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant ones (P<0.1) are underlined. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1for definitions of the species codes.

		Lowland and upland heathland combined			
Species	N	Est	SE	χ^2	P
CU	50	-0.404	0.421	98.31	0.321
L.	20	-2.982	2.228	277.96	<u>0.095</u>
MP	119	0.090	0.025	1278.71	**0.000**
S.	133	0.083	0.047	307.86	<u>0.079</u>
SC	62	0.064	0.072	78.78	0.375

Table 13. *Population growth rate for management of heathland under Tir Cynnal controlled for Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant ones (P<0.1) are underlined, n/a indicates insufficient data to run the analysis. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1 for definitions of the species codes.

		Heathland (habitat and Tir Gofal controlled)			
Species	N	Est	SE	χ^2	P
MP	56	-0.504	0.364	578.07	**0.016**
S.	71	-0.317	0.384	581.84	**0.016**
SC	31	n/a	n/a	n/a	n/a

Table 14. *Population growth rate for scrub management under Tir Gofal. Scrub Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.*
Statistically significant results are highlighted in bold, near-significant ones (P<0.1) are underlined. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1 for definitions of the species codes.

		Scrub			
Species	N	Est	SE	χ^2	P
BC	181	1.254	1.536	0.67	0.413
CC	199	2.641	1.461	3.32	<u>0.068</u>
D.	204	1.840	1.163	2.52	0.112
LI	120	2.901	1.772	2.68	0.102
R.	252	-0.062	0.737	0.01	0.933
SC	62	-8.521	5.309	2.71	0.100
WH	108	0.964	1.295	0.56	0.456
WR	255	1.575	0.731	4.65	**0.031**
WW	191	3.099	0.955	10.72	**0.001**
Y.	42	-0.378	3.920	0.01	0.923

Table 15. *Population growth rate for hedgerow management under Tir Gofal, displayed as parameter estimates ("Est") for the effects of option quantity on population growth rate, their standard errors (each multiplied by 100 for presentation purposes) and significance levels.* Statistically significant results are highlighted in bold. N shows the number of BBS squares with non-zero management in which the species was recorded. See Annex 1 for definitions of the species codes

		Hedgerow			
Species	N	Est	SE	χ^2	P
BF	90	0.003	0.003	77.15	0.380
CH	236	0.001	0.001	130.14	0.254
D.	191	0.002	0.001	483.74	**0.028**
GO	178	-0.001	0.002	51.50	0.473
GR	121	0.006	0.002	976.09	**0.002**
HS	164	0.005	0.001	1657.47	**0.000**
LI	98	0.009	0.003	1208.90	**0.001**
RB	35	0.001	0.006	4.84	0.826
SD	46	0.000	0.002	3.25	0.857
ST	193	0.003	0.001	676.62	**0.009**
WH	107	0.001	0.002	16.96	0.680

Annex 1 English and scientific names of BBS species code.

BBS code	English name	Scientific name	BBS code	English name	Scientific name
B.	Blackbird	*Turdus merula*	P.	Grey Partridge	*Perdix perdix*
BC	Blackcap	*Sylvia atricapilla*	PF	Pied Flycatcher	*Ficedula hypoleuca*
BO	Barn Owl	*Tyto alba*	R.	Robin	*Erithacus rubecula*
BK	Black Grouse	*Tetrao tetrix*	RB	Reed Bunting	*Emberiza schoeniclus*
BT	Blue Tit	*Cyanistes caeruleus*	RG	Red Grouse	*Lagopus lagopus*
BZ	Buzzard	*Buteo buteo*	RK	Redshank	*Tringa totanus*
CB	Corn Bunting	*Emberiza calandra*	RT	Redstart	Phoenicurus phoenicurus
CC	Chiffchaff	*Phylloscopus collybita*	RZ	Ring Ouzel	*Turdus torquatus*
CF	Chough	*Pyrrhocorax Pyrrhocorax*	S.	Skylark	*Alauda arvensis*
CH	Chaffinch	*Fringilla coelebs*	SC	Stonechat	Saxicola rubicola
CU	Curlew	*Numenius arquata*	SD	Stock Dove	*Columba oenas*
D.	Dunnock	*Prunella modularis*	SE	Short-eared Owl	*Asio flammeus*
DN	Dunlin	*Calidris alpina*	SF	Spotted Flycatcher	*Muscicapa striata*
DW	Dartford Warbler	*Sylvia undata*	SG	Starling	*Sturnus vulgaris*
GO	Goldfinch	*Carduelis carduelis*	SH	Sparrowhawk	*Accipiter nisus*
GR	Greenfinch	*Chloris chloris*	SN	Snipe	*Gallinago europeo*
GL	Grey Wagtail	*Motacilla cinerea*	ST	Song Thrush	*Turdus philomelos*
GP	Golden Plover	*Pluvialis apricaria*	TS	Tree Sparrow	*Passer montanus*
GS	Great-Spotted Woodpecker	*Dendrocopos major*	W.	Wheatear	*Oenanthe oenanthe*
HH	Hen Harrier	*Circus cyaneus*	WC	Whinchat	*Saxicola rubetra*
HS	House Sparrow	*Passer domesticus*	WH	Whitethroat	*Sylvia communis*
K.	Kestrel	*Falco tinnunculus*	WO	Wood Warbler	*Phylloscopus sibilatrix*
KF	Kingfisher	*Alcedo atthis*	WP	Woodpigeon	*Columba palumbus*
L.	Lapwing	*Vanellus vanellus*	WR	Wren	*Troglodytes troglodytes*
LI	Linnet	*Carduelis cannabina*	WT	Willow Tit	*Poecile montana*
ML	Merlin	*Falco columbarius*	WW	Willow Warbler	*Phylloscopus trochilus*
MP	Meadow Pipit	*Anthus pratensis*	Y.	Yellowhammer	*Emberiza citrinella*
MR	Marsh Harrier	*Circus aeruginosus*			
MT	Marsh Tit	*Poecile palustris*			
OC	Oystercatcher	*Haematopus ostralegus*			

Annex 2 Tir Gofal options and option names.

Option code	Option name
1A	*SEMI-NATURAL BROADLEAVED WOODLAND: Ungrazed*
1B	*SEMI-NATURAL BROADLEAVED WOODLAND: Lightly Grazed by Livestock*
1C	*SEMI-NATURAL BROADLEAVED WOODLAND: Grazed By Livestock*
2	*SCRUB*
5	*UPLAND HEATH (includes High Mountain Heath)*
6	*LOWLAND AND COASTAL HEATH*
7A	*UNIMPROVED ACID GRASSLAND: Enclosed Lowland*
7B	*UNIMPROVED ACID GRASSLAND: Unenclosed, 200 ha or less*
8	*UNIMPROVED NEUTRAL GRASSLAND*
8A	*UNIMPROVED NEUTRAL GRASSLAND: Haymeadow*
8B	*UNIMPROVED NEUTRAL GRASSLAND:Grazed*
9	*UNIMPROVED LIMESTONE GRASSLAND*
10	*SEMI-IMPROVED GRASSLANDS*
10A	*SEMI-IMPROVED GRASSLANDS: Haymeadow*
10B	*SEMI-IMPROVED GRASSLANDS: Grazed*
11	*MARSHY GRASSLAND*
11A	*MARSHY GRASSLAND: Unenclosed*
18	HEDGEROW RESTORATION
24B	*UNSPRAYED CEREAL, RAPE AND LINSEED CROPS FOLLOWED BY THE RETENTION OF WINTER STUBBLES: Conversion from improved grassland*
25A	*RETENTION OF WINTER STUBBLES IN CEREAL, RAPE AND LINSEED CROPS: After a Conventionally Grown Crop*
25B	*RETENTION OF WINTER STUBBLES IN CEREAL, RAPE AND LINSEED CROPS: After an Unsprayed Crop*
27	*UNSPRAYED ROOTS FOLLOWED BY WINTER GRAZING*
29	*UNCROPPED FALLOW MARGINS ALONGSIDE ARABLE AND ROOT CROPS*
30	*ESTABLISHMENT OF WILDLIFE COVER CROPS*
31D	*CONVERT ARABLE LAND TO GRASSLAND: Improved Coastal Grazing Marsh*
32A1	*CONVERSION OF IMPROVED GRASSLAND TO SEMI-IMPROVED GRASSLAND: Parkland to Semi-improved Haymeadow*
32B2.1	*CONVERSION OF IMPROVED GRASSLAND TO SEMI-IMPROVED GRASSLAND: Grazing Marsh for Lapwing*
32B2.2	*CONVERSION OF IMPROVED GRASSLAND TO SEMI-IMPROVED GRASSLAND:* Grazing Marsh / Lapwing and Wildfowl
34A	*MANAGE IMPROVED GRASSLAND FOR BREEDING LAPWING*
35A	*CONVERSION OF SEMI-IMPROVED GRASSLAND TO UNIMPROVED GRASSLAND: Neutral Grazed*
35B	*CONVERSION OF SEMI-IMPROVED GRASSLAND TO UNIMPROVED GRASSLAND:Acid/Limestone Grazed*
35C	*CONVERSION OF SEMI-IMPROVED GRASSLAND TO UNIMPROVED GRASSLAND: Acid/Limestone Restored by Haycropping*
35D	*CONVERSION OF SEMI-IMPROVED GRASSLAND TO UNIMPROVED GRASSLAND:Neutral Grassland*
36A	*INCREASE WATER LEVELS ON SUITABLE HABITATS AND FEATURES: Improved Land Managed for Conversion to Semi-improved*
36B	*INCREASE WATER LEVELS ON SUITABLE HABITATS AND FEATURES: Marshy Grassland*
36C1	*INCREASE WATER LEVELS ON SUITABLE HABITATS AND FEATURES :Improved Grazing Marsh for Lapwing*
42B	*ESTABLISH NEW SALTMARSHES AND REEDBEDS: New Saltmarsh on Improved land and New Reedbeds on Saltmarshes*

Appendix 5.2: Preliminary analysis of GMEP vegetation plots: can we detect a legacy effect of Tir Gofal on baseline habitat condition?

Introduction

One of the future aims of GMEP is to assess the impact of Glastir on species and habitats. To do this we need to evaluate the baseline condition and any existing variation in habitat condition. One possible source of existing variation is the legacy effects of previous agri-environment schemes. Schemes such as Tir Cynnal and Tir Gofal were the predecessors of Glastir and the prescriptions applied may have affected the habitat condition recorded in the baseline GMEP survey. For example if habitats in Tir Gofal entered the scheme with relatively higher quality or changed positively as a result of managed enhancement this could either limit scope for further enhancement or stimulate further positive change. Either way a significant effect of scheme legacy would need to be included to more fully explain responses to Glastir.

To investigate and quantify legacy effects we analysed differences in vegetation between plots that were on land that had previously been under the Tir Gofal scheme and plots that had never been under Tir Gofal. Tir Gofal was a higher level agri-environment scheme with a focus on enhancing existing habitats. The scheme ran from 1999 to 2012 and had components for both maintenance of existing habitats (“maintain” options) and for conversion or extensification of improved land (“enhance” options) (Medcalf *et al*. 2012). The evidence for a legacy effect on current performance indicators as a result of previous Tir Gofal prescriptions was evaluated from vegetation plot data from the Year 1 and 2 GMEP surveys.

Increased statistical power will arise when Years 3 and 4 of the first GMEP roll are included and so the results of this analysis should be considered preliminary.

Methods

Whether a GMEP survey plot was in land previously under Tir Gofal was assessed using spatial data provided by Welsh Government for the extent for Tir Gofal options. Because the Tir Gofal spatial data has information on which parcels of land were under which options, it was possible to assess whether a GMEP plot had been in land under a specific Tir Gofal option. In the spatial data linear options, such as hedgerow management, are mapped as line features with no width information. To account for inaccuracies in spatial mapping and the potential width of linear features each was assumed to be 10 metres wide. This will allow the effects of linear features to be assessed in plots that are not directly on top of the features e.g. plots next to hedges.

Initial investigation showed that 1043 out of 4135 (25%) of year 1 and 2 GMEP plots were in land that had previously been under a Tir Gofal option. Of these, most had been under options to maintain unenclosed grassland, wet grasslands, raised and blanket bog (Table 16). The 10 options present in more than 40 GMEP squares were investigated further, with the exception of the capital option for funding stock netting. The effect of stock netting is difficult to evaluate as it not possible to know exactly where stock were excluded from.

For each option, or combination of options, in Table 17 differences in a number of habitat condition indicators were evaluated between plots on land that had been under the relevant Tir Gofal option and plots on land where the option had never been applied. Each Tir Gofal option only applies to a certain number of habitats, for example marshy grassland maintenance option (11) only applies to habitat already containing marshy grassland (broad habitat classification fen, marsh and swamp). Therefore, when comparing plots in land that had been in Tir Gofal to land never in Tir Gofal, it is important to only use comparable habitat types. For example, to look at the effect of option 11 on maintaining marshy grassland only plots in fen, marsh and swamp that had never been under Tir Gofal option 11 would be used as the counterfactual. The same process was used to determine counterfactual datasets for other options: the habitat and landscape location (area of habitat or linear feature) impacted by the option were used as criteria to select equivalent plots sampling the same kind of habitat and feature but never subject to Tir Gofal options according to the spatial data layers provided.

The GMEP survey makes use of several different plot types which can be targeted in analyses to ensure only relevant parts of the landscape are assessed. For example, we are only interested in the effects of hedgerow restoration on vegetation recorded in hedgerows and we can use the GMEP plot type to filter the selection to the appropriate plot types (in the case of hedgerow restoration this is D plots). Table 17 shows the plot types included for analysis of each option.

Table 16. *Number of GMEP plots occurring on land that has previously been under Tir Gofal. Each Tir Gofal option is listed separately.*

Option code	Type	Description	Number of GMEP plots
7B	Maintain	Grassland (unenclosed)	121
88A1A	Capital works	Supplement for stock netting	111
11	Maintain	Marshy grassland	93
12	Maintain	Raised and blanket bog	71
40A	Enhance	Establish heathland on acid grassland	63
18	Capital works	Hedgerow restoration	62
7A	Maintain	Grassland (enclosed unimproved acid)	54
5	Maintain	Heaths (upland)	47
1A	Maintain	Ungrazed broadleaf woodland	42
10	Maintain	Semi-improved grassland	38
13	Maintain	Reedbeds, swamps and fens	34
10B	Maintain	Grazed semi-improved grassland	26
1B	Maintain	Lightly grazed broadleaf woodland	23
3BP	Maintain	Improved parkland	23
6	Maintain	Heaths (lowland including coastal)	17
2	Maintain	Scrub management	14
1C	Maintain	Grazed broadleaf woodland	14
32A2	Enhance	Conversion of improved grassland to semi-improved grassland: other improved land to semi-improved haymeadow	13
88A1	Capital works	Timber post and wire fencing	13
12A	Maintain	Blanket bog	12
19A	Capital works	Wall restoration	10
25B	Enhance	Retention of winter stubbles in cereal, rape and linseed crops after an unsprayed crop	10
7C	Maintain	Commons grassland	10

24A	Enhance	Unsprayed cereal, rape and linseed crops	9
8	Maintain	Unimproved neutral grassland	8
45C	Capital works	Heather management (cutting)	8
14A	Maintain	Coastal grazing marsh (improved grassland)	7
8B	Maintain	Unimproved grazed neutral grassland	7
29	Enhance	Uncropped fallow margins alongside arable and root crops	6
38	Enhance	Establishment of streamside corridors	6
10A	Maintain	Semi-improved grassland (haymeadow)	5
16A	Maintain	Grazed maritime cliff and slope	5
31C1	Enhance	Convert arable land to grassland: semi-improved grazed pasture	5
27	Enhance	Unsprayed roots followed by winter grazing	4
24B	Enhance	Unsprayed cereal, rape and linseed crops followed by the retention of winter stubbles	4
53A	Capital works	Scrub clearance (mechanical)	4
50.2	Capital works	Bracken control (chemical)	3
25A	Enhance	Retention of winter stubbles in cereal, rape and linseed crops after a conventionally grown crop	3
32B3	Enhance	Conversion of improved grassland to semi-improved grassland: other improved land to pasture	3
34B	Enhance	Manage improved grassland for over wintering wildfowl	3
26	Enhance	Spring sown cereals undersown with grasses and legumes	2
50.1	Capital works	Bracken control (mechanical)	2
60	Linear	Piping for water supply	2
14/10B	Maintain	Coastal grazing marsh (semi-improved grassland)	2
14/15A	Maintain	Coastal grazing marsh (floodplain grassland scrub)	2
35D	Enhance	Conversion of semi-improved grassland to unimproved grassland: neutral restored by haycropping	2
3CP	Maintain	Arable parkland	2
30	Enhance	Establishment of wildlife cover crops	1

33	Enhance	Create water feature buffer zone on arable	1
14/1A	Maintain	Coastal grazing marsh (improved grassland)	1
15C	Maintain	Saltmarsh (existing un-grazed marsh)	1
16B	Maintain	Maritime cliff and slope (ungrazed)	1
37A	Enhance	Establish new broadleaved woodlands and scrub: establish payment	1
37C	Enhance	Establish new broadleaved woodlands and scrub: plant new woodland	1
3AP	Maintain	Semi-improved parkland	1
Grand Total			**1043**

Table 17. *Options, or combinations of options, for which Tir Gofal legacy effects on habitat condition indicators were evaluated. X and U plots are randomly placed in areas of habitat away from linear features with U plots targeting unenclosed habitats. D plots sample woody linear features including hedgerows. B plots sample field boundaries.*

Option code	Description	Applicable broad habitat	Applicable plot types
1A	Maintain ungrazed broadleaved woodland	Broadleaved woodland	X, Y
5	Maintain upland heath	Dwarf shrub heath, bog	U, X
7A/7B	Maintain unenclosed grassland or enclosed unimproved acid grassland	Acid grassland	U, X
7B/12	Maintain unenclosed grassland or raised and blanket bogs	Bog	U, X, Y
11	Maintain marshy grassland	Fen, marsh, swamp	X, Y, U
18	Hedgerow restoration	Arable and horticulture, improved grassland, neutral grassland	D
40A	Establish heath on acid grassland	Acid grassland	U, X
IMP(B56)	Maintain improved grassland	Improved grassland, neutral grassland	B

The indicators chosen to report on the impacts of each option are shown in Table 18. Indicators were chosen based on both the performance indicators used in Tir Gofal monitoring (Natural Resources Wales 2001) and on the vegetation plot data available from the GMEP survey. Several of the performance indicators used in the Tir Gofal monitoring were not recorded in the GMEP survey and could not be used. Additional indicators were included to aid detection of the expected ecological impact of the option (Table 18).

Table 18. *Indicators used to assess impact of legacy schemes on habitat condition. Where the indicator has an asterisk this indicates an exact or very close match to the performance indicators used in the Tir Gofal Monitoring Report for that option.*

	Tir Gofal option						
Indicator	**1A**	**5**	**7A/7B**	**7B/12**	**11**	**18**	**40A[a]**
AWI richness	x						
Bracken cover			x*	x*			x*
Conifer cover	x						
Dwarf shrub cover		x*		x*			x*
Ellenberg F			x	x	x		x
Ellenberg N	x	x	x	x	x		x
Eriophorum vaginatum cover				x			
Grass : forb ratio		x	x	x	x		x
Non-native cover	x*						
Rush cover			x	x	x*		x
Sphagnum cover				x*	x		x
Total richness	x					x	
Understorey height	x						
Woody cover	x			x			x

[a] Compared to Tir Gofal performance indicators for heathland reversion

The Tir Gofal scheme ran between 1999 and 2012, with new entrants only accepted until 2009. Plots that entered in the first half of the scheme (1999 to 2006) had therefore been under options for longer, and might be expected to show more change, than plots which only entered in the latter half of the scheme (2006-2012). To account for this, differences were investigated between three groups of plots: Never in Tir Gofal, Entered Tir Gofal post-2006 and Entered Tir Gofal pre-2006. Differences in performance indicators between these groups were assessed using linear mixed models where Tir Gofal group (Never in Tir Gofal, entered post-2006, entered pre-2006) was a fixed effect and survey square was a random effect. Where the indicator was a count variable (e.g. total richness) generalised linear mixed models with a Poisson distribution were used. The expectation was for greater differences to be present between counterfactual plots and Tir Gofal plots that had entered earlier rather than later. Without more intensive time series monitoring it is not possible to say however whether such effects are evidence of a positive change over time or better targeting of habitat that entered the scheme earlier.

Results

For the vast majority of indicators (42 out of 45) there was no evidence that plots occurring on land previously subjected to Tir Gofal prescriptions had different values to plots on land which had never been under Tir Gofal (Annex 3). In three cases a significant difference was observed between the Tir Gofal groups (Table 19). For one of these cases, a difference in bracken cover under options 7A and 7B, there was very little data available and therefore the confidence in this result is low. For the other cases where a significant difference was seen, one (total species richness under option 1A) only showed significant differences between the two time periods of Tir Gofal application and no difference from land where Tir Gofal was never applied. This is due to the larger variation in richness in land where Tir Gofal never occurred, even after filtering for habitat and plot type (Figure 2 a). For option 1A (Ungrazed broadleaved woodland) species richness was higher in plots that had entered Tir Gofal before 2006. In one case there were significant differences between plots in land that had entered Tir Gofal before 2006 and plots that had never been under Tir Gofal. Plots that had entered option 5 (maintain upland heath) before 2006 had lower grass:forb ratio in 2013/'14 than plots never in Tir Gofal (Figure Y1 b).

Table 19. *Tests of the difference between each indicator variable in groups of plots that came into Tir Gofal earlier (pre-2006) or later (post-2006) versus counterfactual plots never in Tir Gofal but in equivalent habitat type.*

Option	Indicator	Comparison	Estimated difference	P value
1A	Total species richness	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.39215	0.027227
5	Grass : forb ratio	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-1.82549	0.007668
7A/7B	Bracken cover	Entered Tir Gofal pre-2006 - Never in Tir Gofal	1.544481	0.042537†

† There was very little data to support this result so it is not discussed further.

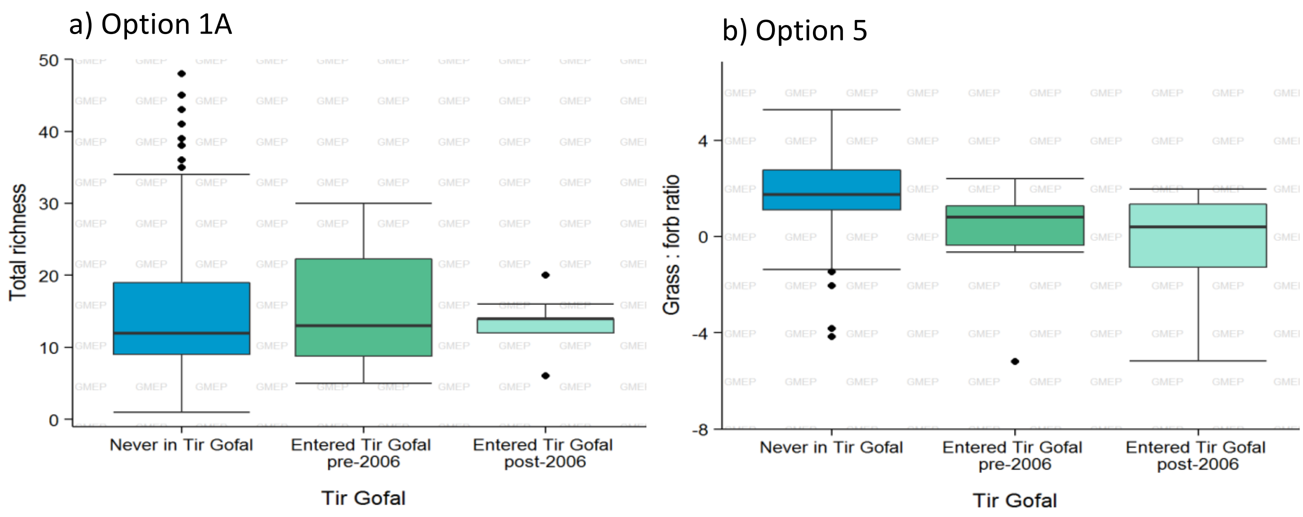

Figure 2. *Significant differences in indicator variables between plots in land that entered Tir Gofal in two different time periods (before or after 2006) and plots that had never been in Tir Gofal.* Corresponding significance tests are presented in Table 19 and total numbers of plots in each analysis in Table 20.

Table 20. *Number of GMEP vegetation plots from the year 1 and 2 surveys that coincided with Tir Gofal options and counterfactual plots never in Tir Gofal.*

Option code	Number of plots in option	Number of plots in counterfactual
11	28	183
18	33	534
1A	21	221

40A	28	170
5	19	217
7A/7B	55	143
7B/12	38	156

Discussion

In interpreting the impacts of legacy schemes on the baseline conditions observed in GMEP squares it is important to note that the GMEP survey was not designed to evaluate legacy scheme effects and therefore our results may differ from the monitoring conducted by past agri-environment schemes. In particular, we only attempted to detect the signal of Tir Gofal in the first two years of Gmep survey data. Our sample sizes were therefore small compared to previous more intensive evaluation of Tir Gofal in which a wider range of scheme effects were detected (Medcalf et al 2012). In addition, we have only evaluated one past scheme and our sample size is small for most Tir Gofal options, therefore caution should be used in evaluating the results. However, despite these concerns, it is important to consider the potential effects of previous agri-environment schemes on the baseline conditions recorded by the GMEP survey. If there was evidence that Tir Gofal was responsible for differences in the baseline levels of indicators recorded then it would be important to account for this effect in future analyses of Glastir impact to avoid incorrectly attributing change. Our analysis suggests that, within the first and second years of GMEP recording, there was little evidence that Tir Gofal had led to lasting changes in the indicators measured. Only three out of 47 option-indicator combinations showed any influence of Tir Gofal occurrence or duration and only two of these showed differences between plots that had been in Tir Gofal and those that had not which were well supported by the data (i.e. excluding the difference in bracken cover in option 7A/7B).

Grass : forb ratio was found to be significantly lower in upland heathlands that had been maintained under Tir Gofal option 5 than in heathlands that had never been in Tir Gofal. Low grass:forb ratio is considered to be indicative of better ecological condition, as a high proportion of graminoids is often a result of excessive nutrient enrichment or over-grazing. Unfortunately, grass : forb ratio was not used as a performance indicator in the Tir Gofal monitoring surveys and therefore a direct comparison with this evaluation cannot be made. However, the Tir Gofal monitoring report (Medcalf et al 2012) did conclude that heathland sites were generally being well protected by Tir Gofal, with 45% of sites improving in ecological condition. The report also concluded that changes in condition in heathland were likely to occur in the long term as most changes were observed in only the second of two resurveys, eight years after the start of Tir Gofal. Our results support this conclusion, with only plots that entered Tir Gofal before 2006 having a significantly lower grass:forb ratio.

Overall our results suggest that, in most cases, there is no evidence that Tir Gofal has led to long term changes in the indicators assessed which would need to be accounted for in any analysis of change due to Glastir measures. However, this result does not necessarily mean that the Tir Gofal scheme did not have any long term impacts. At this stage it is more likely to reflect our inability to detect effects given the small sample size available. Hence, based on just years 1 and 2, we do not have enough coincidence between GMEP plots and past Tir Gofal option land to adequately test whether the positive changes seen in grasslands, woodland and blanket bog in Medcalf et al (2012) are reflected in the GMEP sample. These analyses will have greater power when all four years of data have been accumulated. At that point we will re-run these analyses in preparation for analysing change in time once the second roll starts to yield repeat data.

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Annex 3. Predicted indicator values and significance tests for all 47 indicator/option combinations between three Tir Gofal groups: Never in Tir Gofal, Entered Tir Gofal pre-2006 and Entered Tir Gofal post-2006. Rush cover comprises cover *of J.effusus, maritima, inflexus, conglomeratus, acutiflorus*. Woody cover comprises trees and shrubs including Bramble and Roses but excluding dwarf shrubs.

Option code	**Indicator**	**Estimate of indicator in each Tir Gofal group**				**Differences in indicators between Tir Gofal groups**		
11	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	3.939	3.735	4.144	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.245	0.675
		Entered Tir Gofal pre-2006	3.694	3.139	4.249	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.612	0.188
		Entered Tir Gofal post-2006	3.327	2.635	4.020	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.367	0.662
11	Grass : forb ratio	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	-0.031	-0.338	0.275	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.034	0.997
		Entered Tir Gofal pre-2006	0.003	-0.910	0.915	Entered Tir Gofal post-2006 - Never in Tir Gofal	1.025	0.278
		Entered Tir Gofal post-2006	0.993	-0.321	2.307	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.991	0.423
11	Rush cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	2.673	2.252	3.094	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-1.011	0.297
		Entered Tir Gofal pre-2006	1.662	0.372	2.952	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.869	0.642
		Entered Tir Gofal post-2006	1.804	-0.091	3.700	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.143	0.991
11	*Sphagnum* cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.589	1.117	2.062	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.439	0.815
		Entered Tir Gofal pre-2006	1.150	-0.222	2.523	Entered Tir Gofal post-2006 - Never in Tir Gofal	1.324	0.357
		Entered Tir Gofal post-2006	2.913	1.013	4.814	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	1.763	0.276
11	Ellenberg F	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	7.207	7.112	7.302	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.250	0.239
		Entered Tir Gofal pre-2006	7.457	7.164	7.751	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.130	0.825
		Entered Tir Gofal post-2006	7.337	6.907	7.766	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.121	0.888
18	Total richness	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	5.300	4.230	6.370	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.062	0.815
		Entered Tir Gofal pre-2006	5.639	4.408	6.870	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.066	0.859
		Entered Tir Gofal post-2006	4.961	3.670	6.253	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.128	0.696

1A	AWI richness	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	2.590	1.439	3.740	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.377	0.070
		Entered Tir Gofal pre-2006	3.776	2.360	5.192	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.176	0.723
		Entered Tir Gofal post-2006	2.171	0.569	3.774	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.553	0.128
1A	Conifer cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.335	0.173	0.496	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.065	0.982
		Entered Tir Gofal pre-2006	0.270	-0.424	0.963	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.335	0.691
		Entered Tir Gofal post-2006	0.000	-0.801	0.801	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.270	0.867
1A	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	5.183	5.045	5.320	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.049	0.972
		Entered Tir Gofal pre-2006	5.133	4.700	5.567	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.089	0.933
		Entered Tir Gofal post-2006	5.272	4.765	5.778	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.138	0.907
1A	Non-native cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.148	0.766	1.530	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.348	0.890
		Entered Tir Gofal pre-2006	1.495	0.005	2.986	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.285	0.944
		Entered Tir Gofal post-2006	0.862	-0.875	2.600	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.633	0.844
1A	Total richness	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	13.609	12.534	14.683	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.127	0.374
		Entered Tir Gofal pre-2006	15.459	14.245	16.672	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.265	0.065
		Entered Tir Gofal post-2006	10.444	9.173	11.715	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.392	0.027
1A	Understorey height	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.861	1.691	2.032	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.063	0.980
		Entered Tir Gofal pre-2006	1.799	1.146	2.451	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.336	0.658
		Entered Tir Gofal post-2006	2.197	1.436	2.959	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.399	0.704
1A	Woody cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	10.093	9.629	10.557	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.145	0.989
		Entered Tir Gofal pre-2006	10.237	8.255	12.220	Entered Tir Gofal post-2006 - Never in Tir Gofal	1.431	0.440
		Entered Tir Gofal post-2006	11.524	9.234	13.815	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	1.287	0.672

40A	Bracken cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.478	0.176	0.780	Entered Tir Gofal pre-2006 - Never in Tir Gofal	1.099	0.327
		Entered Tir Gofal pre-2006	1.577	0.050	3.103	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.684	0.253
		Entered Tir Gofal post-2006	1.162	0.324	2.001	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.414	0.881
40A	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	3.079	2.926	3.232	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.089	0.933
		Entered Tir Gofal pre-2006	2.990	2.473	3.507	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.142	0.626
		Entered Tir Gofal post-2006	3.221	2.893	3.549	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.231	0.711
40A	Grass : forb ratio	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.874	1.604	2.143	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.167	0.953
		Entered Tir Gofal pre-2006	2.040	0.900	3.180	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.270	0.705
		Entered Tir Gofal post-2006	2.144	1.458	2.829	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.103	0.986
40A	Rush cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.872	0.633	1.110	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.472	0.779
		Entered Tir Gofal pre-2006	0.400	-0.991	1.791	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.185	0.852
		Entered Tir Gofal post-2006	0.687	0.038	1.335	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.287	0.925
40A	*Sphagnum* cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.654	0.411	0.897	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.592	0.617
		Entered Tir Gofal pre-2006	0.062	-1.192	1.316	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.276	0.707
		Entered Tir Gofal post-2006	0.377	-0.299	1.054	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.315	0.896
40A	Dwarf shrub cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.483	1.149	1.816	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.322	0.911
		Entered Tir Gofal pre-2006	1.161	-0.406	2.728	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.448	0.589
		Entered Tir Gofal post-2006	1.035	0.131	1.938	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.126	0.989
40A	Woody cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.406	0.193	0.619	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.924	0.172
		Entered Tir Gofal pre-2006	-0.518	-1.538	0.503	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.030	0.994
		Entered Tir Gofal post-2006	0.436	-0.146	1.018	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.953	0.233

40A	Ellenberg F	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	6.116	6.001	6.231	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.180	0.740
		Entered Tir Gofal pre-2006	5.936	5.446	6.426	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.210	0.320
		Entered Tir Gofal post-2006	5.906	5.612	6.200	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.030	0.994
5	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	2.291	2.170	2.412	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.099	0.917
		Entered Tir Gofal pre-2006	2.192	1.690	2.693	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.012	0.998
		Entered Tir Gofal post-2006	2.279	1.867	2.690	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.087	0.959
5	Grass : forb ratio	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.858	1.527	2.190	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-1.825	0.008
		Entered Tir Gofal pre-2006	0.033	-1.181	1.246	Entered Tir Gofal post-2006 - Never in Tir Gofal	-1.141	0.100
		Entered Tir Gofal post-2006	0.717	-0.396	1.830	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.684	0.661
5	Dwarf shrub cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	5.284	4.645	5.924	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.852	0.760
		Entered Tir Gofal pre-2006	6.136	3.707	8.566	Entered Tir Gofal post-2006 - Never in Tir Gofal	1.479	0.300
		Entered Tir Gofal post-2006	6.763	4.740	8.786	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.626	0.910
7A/7B	Bracken cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.397	0.086	0.709	Entered Tir Gofal pre-2006 - Never in Tir Gofal	1.544	0.043
		Entered Tir Gofal pre-2006	1.942	0.687	3.197	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.533	0.169
		Entered Tir Gofal post-2006	0.931	0.389	1.473	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-1.011	0.290
7A/7B	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	3.067	2.910	3.224	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.101	0.869
		Entered Tir Gofal pre-2006	2.965	2.549	3.382	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.125	0.442
		Entered Tir Gofal post-2006	3.192	2.966	3.417	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.226	0.548
7A/7B	Grass : forb ratio	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.865	1.585	2.146	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.086	0.981
		Entered Tir Gofal pre-2006	1.951	1.022	2.881	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.154	0.776
		Entered Tir Gofal post-2006	2.019	1.566	2.472	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.068	0.990

7A/7B	Rush cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.802	0.541	1.062	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.180	0.951
		Entered Tir Gofal pre-2006	0.982	-0.195	2.159	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.125	0.879
		Entered Tir Gofal post-2006	0.926	0.477	1.376	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.056	0.996
7A/7B	Ellenberg F	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	6.125	6.005	6.246	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.017	0.996
		Entered Tir Gofal pre-2006	6.142	5.743	6.541	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.160	0.230
		Entered Tir Gofal post-2006	5.965	5.770	6.159	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.177	0.681
7B/12	Bracken cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.092	-0.006	0.191	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.081	0.959
		Entered Tir Gofal pre-2006	0.011	-0.580	0.602	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.083	0.705
		Entered Tir Gofal post-2006	0.010	-0.182	0.202	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.001	1.000
7B/12	*Eriophorum vaginatum* cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	2.932	2.423	3.441	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.929	0.780
		Entered Tir Gofal pre-2006	3.861	1.083	6.639	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.223	0.900
		Entered Tir Gofal post-2006	2.709	1.758	3.660	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-1.152	0.705
7B/12	Ellenberg N	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.934	1.847	2.021	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.039	0.989
		Entered Tir Gofal pre-2006	1.973	1.407	2.539	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.028	0.953
		Entered Tir Gofal post-2006	1.906	1.731	2.081	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.067	0.971
7B/12	Grass : forb ratio	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	1.912	1.564	2.259	Entered Tir Gofal pre-2006 - Never in Tir Gofal	1.283	0.283
		Entered Tir Gofal pre-2006	3.195	1.505	4.885	Entered Tir Gofal post-2006 - Never in Tir Gofal	0.556	0.219
		Entered Tir Gofal post-2006	2.467	1.845	3.090	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.728	0.691
7B/12	Rush cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.561	0.281	0.841	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.195	0.974
		Entered Tir Gofal pre-2006	0.367	-1.429	2.162	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.144	0.885
		Entered Tir Gofal post-2006	0.418	-0.144	0.979	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.051	0.998

7B/12	*Sphagnum* cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	5.304	4.711	5.897	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-1.032	0.822
		Entered Tir Gofal pre-2006	4.272	0.795	7.749	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.996	0.246
		Entered Tir Gofal post-2006	4.308	3.164	5.452	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	0.036	1.000
7B/12	Dwarf shrub cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	3.922	3.132	4.712	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.539	0.946
		Entered Tir Gofal pre-2006	3.383	-0.063	6.829	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.583	0.666
		Entered Tir Gofal post-2006	3.339	2.024	4.654	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.044	1.000
7B/12	Woody cover	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	0.109	0.013	0.206	Entered Tir Gofal pre-2006 - Never in Tir Gofal	0.264	0.544
		Entered Tir Gofal pre-2006	0.373	-0.130	0.875	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.086	0.632
		Entered Tir Gofal post-2006	0.023	-0.153	0.199	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.350	0.379
7B/12	Ellenberg F	Tir Gofal group	Estimated value	Lower estimate	Upper estimate	Test	Estimated difference	P value
		Never in Tir Gofal	7.198	7.087	7.309	Entered Tir Gofal pre-2006 - Never in Tir Gofal	-0.057	0.986
		Entered Tir Gofal pre-2006	7.141	6.431	7.851	Entered Tir Gofal post-2006 - Never in Tir Gofal	-0.100	0.686
		Entered Tir Gofal post-2006	7.098	6.876	7.321	Entered Tir Gofal post-2006 - Entered Tir Gofal pre-2006	-0.043	0.992

Appendix 5.3: Long-term Population Trends of Birds in Wales

Gavin M. Siriwardena and Daria Dadam
British Trust for Ornithology, The Nunnery, Thetford, Norfolk IP24 2LW.
Updated May 2015

Introduction

Annual breeding bird monitoring occurs in Wales independently of GMEP, under the BTO/JNCC/RSPB Breeding Bird Survey (BBS), a scheme using volunteer survey effort to cover a random selection of 1km squares every year. This survey is designed to provide long-term, large-scale monitoring of bird and larger mammal populations, and it can be used to test for signals of management, such as agri-environment schemes, at large temporal and spatial scales (e.g. Davey et al. 2010, Baker et al. 2012). However, the survey method is not intensive and it does not provide reliable information on absolute annual population sizes in local survey squares, or of the locations of bird with respect to fine-scale habitat patches, so the bespoke surveys under GMEP are essential for testing Glastir effectiveness. Nevertheless, the national coverage of BBS monitoring makes it ideal for revealing broad population changes of widespread species.

Here, up-to-date background population changes for the whole of Wales are presented for the life of the BBS to date, i.e. from 1994 to 2013. Data typically take around a year to be processed and made ready for analysis, but it is intended that this document be kept up to date throughout GMEP as a source of reference for all-Wales population trends among bird species of interest. The population trends shown are estimates of changes in relative abundance across the whole of Wales, so are appropriate for assessing progress towards statutory conservation targets.

The population trends shown are mostly taken from the BTO's annual Bird Trends Report (http://www.bto.org/about-birds/birdtrends), with the addition of data on some species that are recorded less commonly than is required for the standards of that report and data from other sources for very rare species (see below). Details of the BBS survey methods and of the analytical techniques used can be found there (http://www.bto.org/about-birds/birdtrends/2014/methods/breeding-bird-survey). In brief, however, the survey is based on a random sample of 1km squares, stratified by observer density, which are visited twice each year. On each visit, 2km of transect is walked and maximum counts per square per year are used to estimate annual indices of relative abundance, which are the back-transformed year effects from a log-linear Poisson model of count as a function of categorical site and year effects. Most conservation applications are concerned with long-term, underlying population trends, rather than short-term changes driven by weather (for example). Changes are therefore presented both as annual index values (blue squares) and as smoothed trends (green lines). Confidence intervals (green shaded areas) are estimated by bootstrapping by survey square.

The species shown are those that are of general interest for conservation or specific interest for potential effects of Glastir, together with as many other Section 42 priority species as possible. For the Bird Trends report, species present in fewer than 30 BBS squares are excluded because small sample sizes provide less reliable results. This is particularly the case in a survey like the BBS, where turnover of squares in the sample can lead to rapid changes in pattern between years if squares with contrasting local populations of a rare species drop in and out. However, the choice of a 30-square threshold is arbitrary and a lot of the uncertainty associated with small samples is reflected in increases in the breadth of the confidence intervals around the smoothed trends. For the purposes of reporting the maximum amount of information on trends in Wales, therefore, species of interest with smaller sample sizes but for which the calculation of annual index values was still tractable are included below. Nevertheless, indices for species for which samples fell below the 30-square threshold are less reliable and these species are flagged; the trends indicated for them should be interpreted with caution.

Even after including the rarer species in BBS, no national monitoring data are available for a number of priority species for conservation in Wales. Intensive surveys are conducted annually for Chough (A. Cross & A. Stratford, pers. comm.) and these data will be summarized here in due course. Data are available for some further species from bespoke surveys; where these results are published, they are incorporated below (for Hen Harrier and Golden Plover), while unpublished data will be added when provided by the data holders (notably RSPB). For other key species not effectively extinct in Wales, but sufficiently uncommon to be noteworthy species for recreational birdwatchers, informal count records are collated by county in the annual Birds in Wales report produced by the Welsh Ornithological Society. The species considered are Twite, Golden Plover, Hawfinch, Hen Harrier, Ring Ouzel, Tree Sparrow, Turtle Dove and Yellow Wagtail. These data are not standardized and are likely to incorporate considerable variation in effective sampling effort. However, it is likely that birdwatchers visit the same sites each year and those who are regular contributors to bird reports probably have reasonably regular habits from year to year. Overall, it would be unwise to interpret the fine details of changes in these counts between years as reliable, but gross changes in abundance within very small populations should be apparent, provided that coverage by county is reasonably consistent over time and all relevant counties appear in the annual data fairly frequently. Hence, data were extracted from the Birds in Wales reports from 1995 to 2012 (excluding 2001, when countryside closure due to foot-and-mouth disease restricted access for birdwatchers) for birds likely to be breeding in Welsh counties. The biology and phenology of movement of each species were used to decide whether an entry in a report referred to a breeding bird. Only entries with a defined number of individuals were included and reports of “pairs” or “territories” were interpreted as representing two birds each. If a range of counts was provided, the maximum was taken as the annual number for the location concerned. A reporting bias was present in some years and/or locations in which, due to birds being numerous, numbers of individuals were not reported. Another possible bias was due to lack of confirmed zero counts: a species that had not been reported from a location was treated as missing value rather than as confirmed absence, unless absence was reported explicitly. Only counties reporting counts in two or more years were included. This may result in an apparent downturn in population which is, in fact, an artefact of the reporting methodology of the Bird Reports used. The impact of this problem was minimized by the statistical approach that was used, assuming that population changes were uniform in direction across the counties from which counts were reported and that the major centres of population were covered in some years at least. Nevertheless, it is important to recognize that the report data are no substitute for structured sampling or population censuses and it would be unwise to use them as more than a general guide to population trajectories, as opposed to definitive information about (relative) population size. In the future, these analyses should be replaced by more standardized monitoring if it becomes possible, or by analyses of data gathered within BirdTrack (www.birdtrack.net).

Annual county-specific numbers of birds were modelled as a function of year and county identity, as categorical factors, specifying Poisson errors and a log link function, weighting by the number of counties contributing data in each year. Back-transformed annual year effect estimates were then plotted against year to show temporal trends in abundance. This method is the same as that normally used for population index generation using national survey data such as from the BBS. To summarize population trends over time, linear trends were fitted through the annual index values using least squares regression, once again weighting by the number of counties contributing data in each year as an index of annual data quality. For Twite, data were present from only one county; therefore the trend shows the raw number of birds plotted against year.

Trends from the best available of the sources described above are shown for each species, using data from across the whole of Wales, together with BBS trends for the whole of the UK if they are appreciably different from the Wales ones. The vertical lines on each graph show the periods used to produce trend summaries in GMEP reporting. The text simply then describes the broad patterns seen; for more detail and information on variation in demographic parameters where available, please see the BTO Bird Trends report website (follow links for each species accounts). In addition, summaries of range change revealed from Bird Atlas 2007-2011 (Balmer et al. 2013), which considered distributions at the 10km square scale across the whole of Wales and how these have changed over four decades, are summarized for the rarest species.

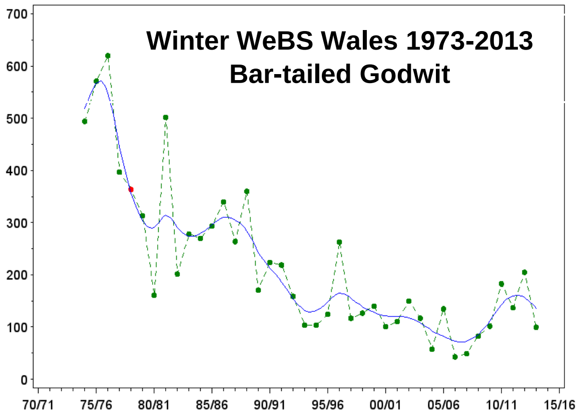
All of the above relates to breeding bird populations. However, eight Section 42 priority species are so designated because of the wintering populations. These species (Bar-tailed Godwit, Bewick's Swan, Black-headed Gull, Common Scoter, Dark-bellied Brent Goose, Greenland Greater White-fronted Goose, Herring Gull and Ringed Plover) are all surveyed annually by the BTO/JNCC Wetland Bird Survey (WeBS) in coastal and inland wetland habitats. Details of WeBS methodology can be found at http://www.bto.org/volunteer-surveys/webs, but it is a volunteer survey that operates throughout the year, aiming to provide total population counts for coastal habitats and to cover a representative sample of inland stillwaters. Counts are made monthly and the winter data presented here collate records from October-March each year for sites in Wales.

Three of the wetland Section 42 species also breed in Wales, but are not monitored effectively by the BBS. For these species (Black-headed Gull, Herring Gull and Ringed Plover), breeding season WeBS trends (derived from counts from April to June) are also presented.

All WeBS trends are shown for the maximum run of data collected under the scheme for each species, but discussion of the trends focuses on the periods from 1994, as for the other trends. Dots and dashed lines show inter-annual changes, while solid lines show smoothed trends. Green dots are drawn entirely from empirical data, while red dots show where an appreciable portion of the sample has been imputed due to gaps in survey coverage.

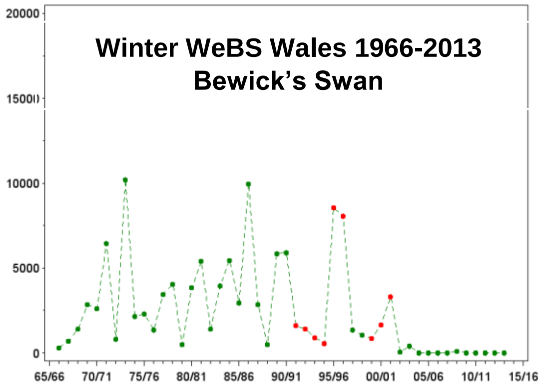
Species accounts (in alphabetical order)

BAR-TAILED GODWIT (Limosa lapponica)



The Bar-tailed Godwit population wintering in Wales has been rather stable overall since the mid-1990s, but this follows a sustained period of decline. Recent changes may show the beginning of a recovery of the population, but this is currently unclear.

BEWICK'S SWAN (Cygnus columbianus bewickii)

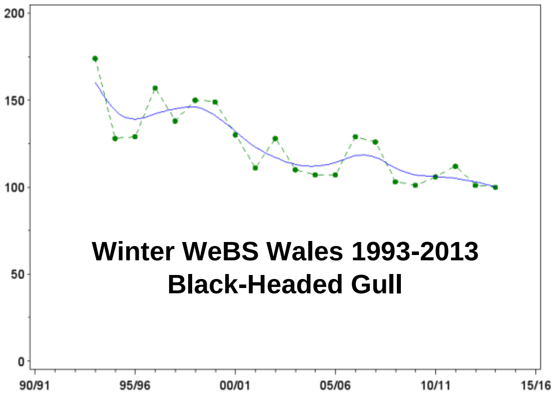


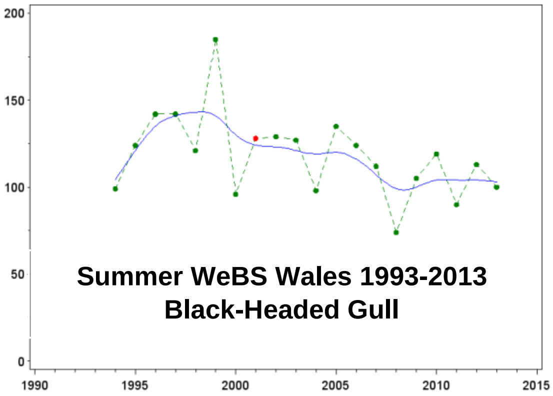
The global population of Bewick's Swan has declined by 27% and there may also have been a tendency for the species to winter further east than was the case historically (Balmer et al. 2013). Wales is at the western edge of the wintering range and the broad scale changes have been reflected in the species' almost total disappearance as a significant wintering bird: only scattered records were reported for the 2007-11 Bird Atlas (Balmer et al. 2013). The winter WeBS trend also reflects this pattern, with counts effectively being zero since 2002-03. Note that the latter means that the species cannot contribute to the summary population trend indicator in the GMEP reporting.

BLACK GROUSE (Tetrao tetrix)

The Black Grouse distribution in Wales has contracted considerably since 1970, with the species having been lost from more southerly upland areas now to be concentrated in Snowdonia and the Clywdian Hills, although the latter area has seen some gains in abundance (Balmer et al. 2013). There are too few Bird Report records for this species to allow any analyses of incidental data, but RSPB have conducted periodic surveys that inform about population changes in Wales and the aim is to incorporate these data here in due course.

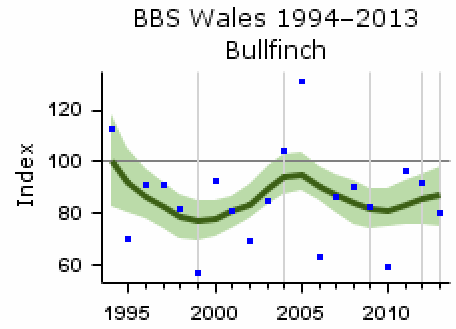
BLACK-HEADED GULL (Larus ridibundus)





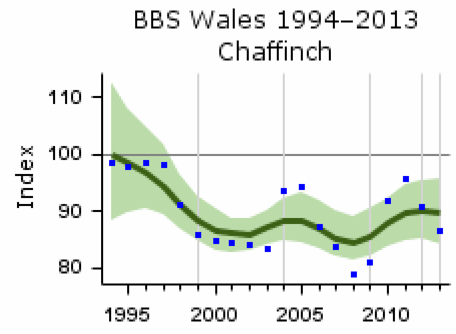
Both the breeding and wintering Black-Headed Gull populations in Wales have declined since the mid-1990s, although the pattern is clearer and stronger, being subject to smaller fluctuations, in wintering numbers. This may be the result of sampling error, with colonies either being somewhat mobile, or sites with differently sized colonies dropping in and out of the survey sample over time.

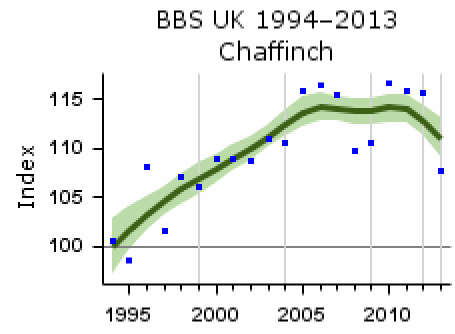
BULLFINCH (Pyrrhula pyrrhula)



The Bullfinch population trend in Wales reflects trends in the wider UK. In England at least, there was a steep decline that started before the inception of BBS; in Wales, as in England, populations may now be increasing, or perhaps fluctuating around a stable level. [More detail]

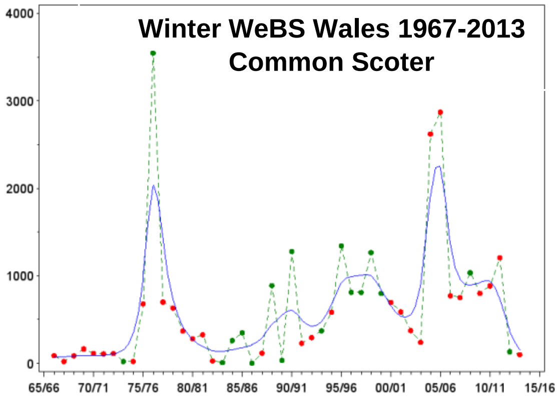
CHAFFINCH (*Fringilla coelebs*)





The species has been showing a fluctuating population trend in Wales, in contrast with the upward UK trend. [More detail]

COMMON SCOTER (Melanitta nigra)



There has been some uncertainty over wintering Common Scoter numbers around Wales, as shown by the large number of imputed counts in the time series (red dots). The data suggest that numbers have fluctuated considerably over time, but with a tendency to increase since the early 1990s, notwithstanding low counts in the most recent two winters.

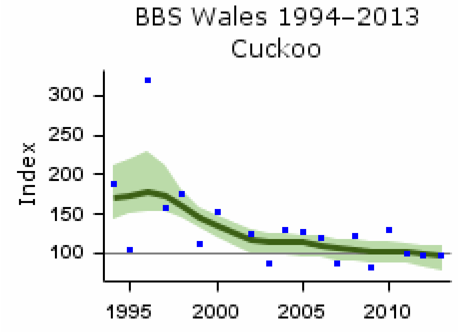
CORN BUNTING (Emberiza calandra)

There is no BBS trend for Corn Bunting produced for Wales and it is now extinct as a breeding species, reflecting the long-term trend across the UK, which has shown a steep decline during the BBS period and before. [More detail] Bird Atlas 2007-11 (Balmer et al. 2013) shows the losses of (already sparse) pockets of breeding Corn Buntings during the 1970s and 1980s, with the final breeding locations being lost between 1991 and 2011. Occasional birds are recorded in Wales, near the English border, so recolonization is possible given appropriate habitat management.

CHOUGH (Pyrrhocorax pyrrhocorax)

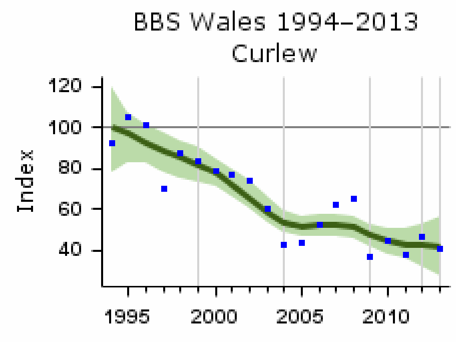
No BBS trend can be produced for chough in Wales because the species is too localized. Survey data may be available from independent volunteer surveyors, which it is hoped will be available here for Ceredigion and northwards in Spring 2015, with data to be added for Dyfed in due course, pending negotiation. Bird Atlas 2007-11 (Balmer et al. 2013) shows increases in the Chough breeding range, especially since 1991, with newly recorded locations on the south coast in particular. The bulk of the population is found in Snowdonia and on the west coast, particularly in Gwynedd and Pembrokeshire.

CUCKOO (Cuculus canorus)



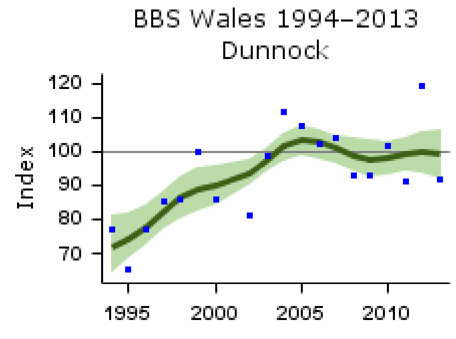
The UK Cuckoo population has been in decline since the mid-1980s and the Welsh population shows a consistent pattern since the inception of BBS. [More detail]

CURLEW (Numenius arquata)



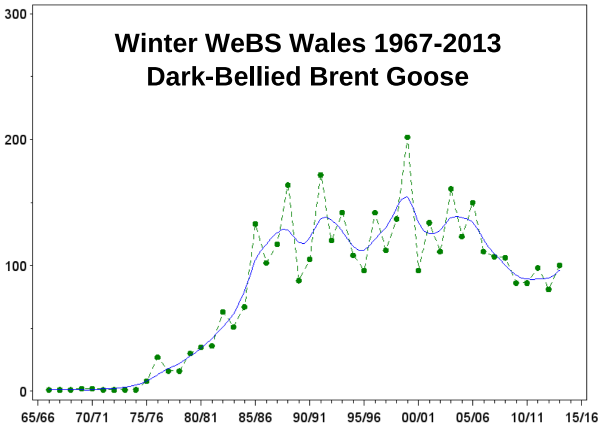
Curlew in Wales has been in long-term decline throughout the BBS period, in line with the pattern seen across the whole of the UK. [More detail]

DUNNOCK (Prunella modularis)



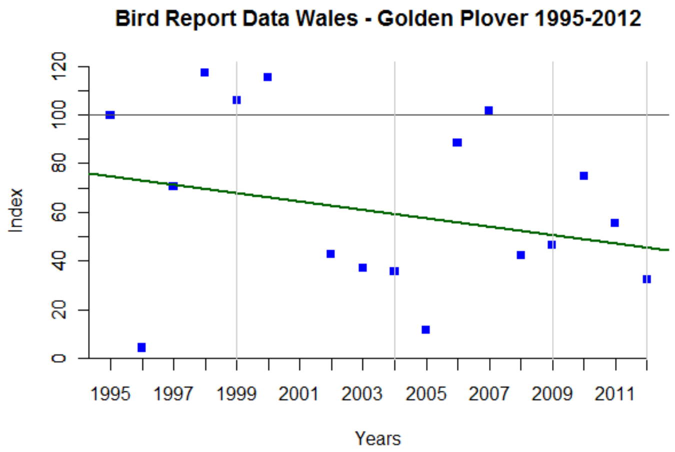
The Dunnock population trend in Wales has matched the wider UK one, showing an increase during the 1990s and early 2000s, followed by a period of stability. All of this follows a steep population decline from the mid-1970s.

DARK-BELLIED BRENT GOOSE (Branta bernicla bernicla)



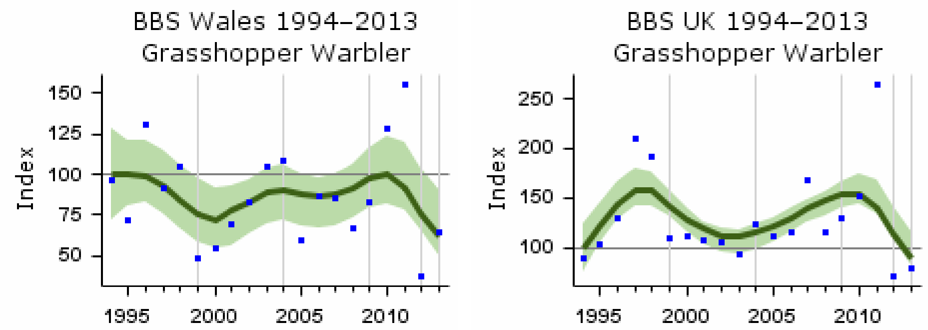
The Dark-Bellied Brent Goose population in Wales has fallen over the last ten years, following a pronounced increase in the 1970s and 1980s that was shared by a number of arctic-breeding goose populations and a subsequent period of stability.

GOLDEN PLOVER (Pluvialis apricaria)



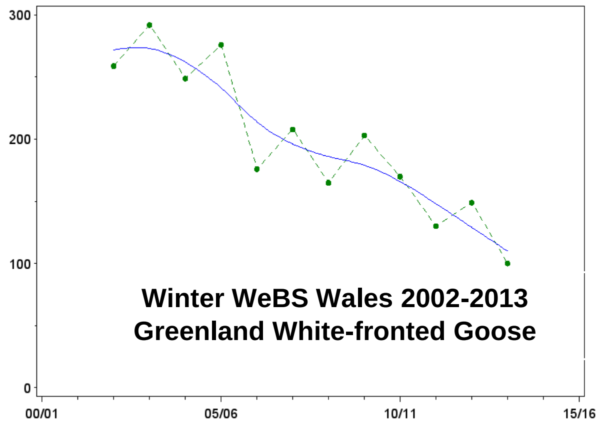
Golden Plover breeding densities are lower in suitable habitat in Wales than in the species' core areas in the UK in Scotland, but long-term changes show little clear gross change in abundance or in range (Balmer et al. 2013). However, an RSPB survey in 2007 found just 36 pairs in Wales, which was interpreted as a decline of c. 80% from the late 1970s (although a true baseline was not available for comparison, Johnstone et al. 2008). Bird Report data also suggest a possible general population decline between 1995 and 2012, which reflects the trend for UK (Baillie et al 2014) [More detail], but the pattern is not strong. Nine vice counties contributed to the Bird Report trend and, whilst none of them had reports in all years, three (Brecon, Radnor and Meirionnydd) contributed with at least nine years and Carmarthen contributed with six years, while the remaining five vice counties had records for four or fewer years. No data were available for 2001, due to the foot-and-mouth disease outbreak preventing countryside access. The outlier in 1995 is due to a large count in one of the vice counties in that year; without such large initial index the decline would appear shallower.

GRASSHOPPER WARBLER (Locustella naevia)



There has been no clear trend in Grasshopper Warbler numbers in Wales. Note that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares), so the apparent detailed changes should be interpreted with caution. However, the broad similarity to the wider UK pattern suggests that there trend has not been strongly affected by sampling bias. [More detail]

GREENLAND GREATER WHITE-FRONTED GOOSE (Anser albifrons flavirostris)

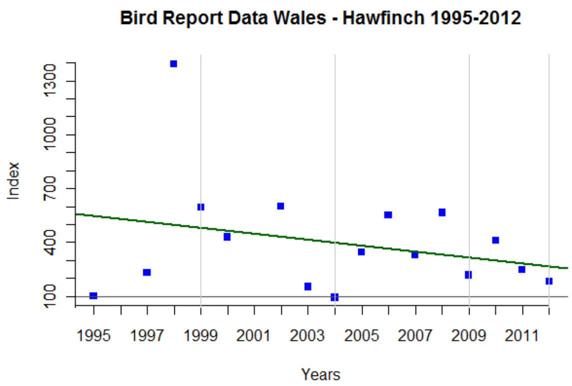


The wintering Greenland Greater White-Fronted Goose population in Wales has shown a sustained decline in Wales since 2000, when annual monitoring became possible. This reflects a broader decline throughout the subspecies' wintering range over this period, although it follows a period of increase. [More detail]

GREY PARTRIDGE (Perdix perdix)

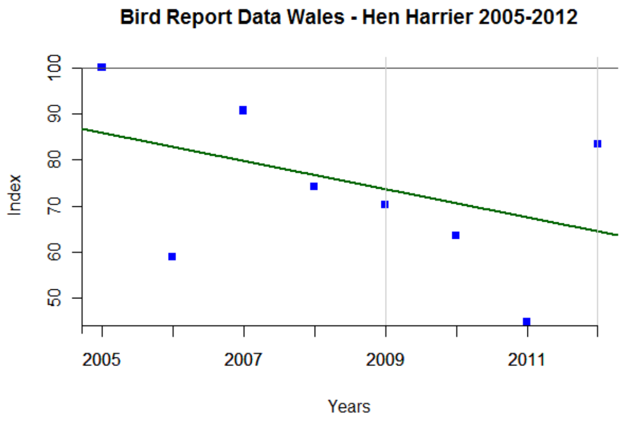
Grey partridge is too rare in Wales to be monitored by the BBS, having largely disappeared in the 1970s and 1980s, mirroring the long-term decline across the UK as a whole. [More detail] Bird Atlas 2007-11 (Balmer et al. 2013) shows continuing losses of breeding locations throughout Wales since 1972, with the remaining strongholds being Anglesey, the far south-east and along the English border. Insufficient records are available in Bird Reports to allow analysis.

HAWFINCH (Coccothraustes coccothraustes)



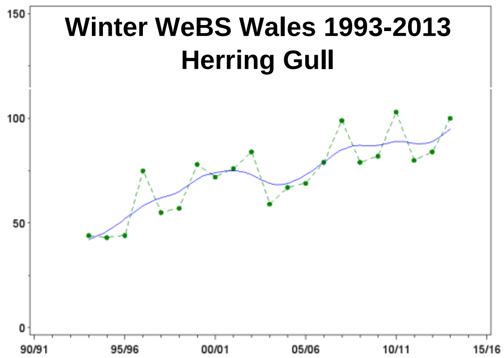
Hawfinch has a patchy distribution in Wales (Balmer et al. 2013), following an irregular pattern of gains and losses of breeding locations since 1972. It is too rare to be monitored by the BBS, but is now mostly found in south Gwynedd, with other, isolated records coming from sites in mid-Wales and the far south-east (Balmer et al. 2013). The trend from bird report data for Hawfinch shown suggests a declining population between 1995 and 2012, but is influenced by an outlier year in 1998, when a high index value appears to have been driven by high numbers reported birds in one vice-county. The amount of data available varied between vice-counties but the species was recorded during the breeding months in twelve of them. While none of the vice-counties had reported the species for all of years considered, Gwent had records for 11 of the 18 years considered, and Glamorgan and Meirionnydd for eight and seven, respectively. All years were represented in the dataset but only a maximum of four vice-counties provided data each year.

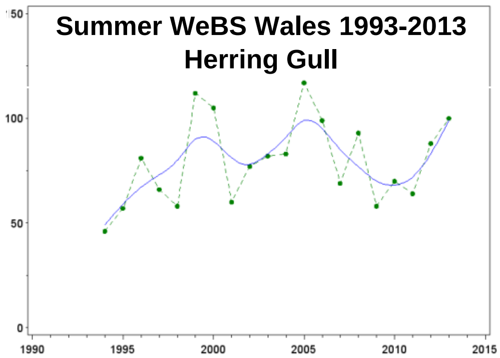
HEN HARRIER (Circus cyaneus)



Bird report data suggest that the Hen Harrier population in Wales has declined between 2005 and 2012. This contrasts with recent findings of a survey in the UK that showed an increase by almost 33% in Wales between 2004 and 2010 (Hayhow et al. 2013). The number of proven and possible pairs in the aforementioned survey was 57 (Hayhow et al. 2013), and data from the 2010 Welsh Bird Report also suggest approximately 51 pairs. Since the Bird Report records are unstandardized and unstructured, they are less reliable than the targeted surveys, so should be treated with caution. However, they may be the only source of annual data in the future. Six vice-counties contributed to the trend reported above and two of them, Meirionnydd and Montgomeryshire, contributed with all years. All years were represented in the dataset, and data for four years (2007, 2009, 2010 and 2012) came from at least five vice-counties. [More detail].

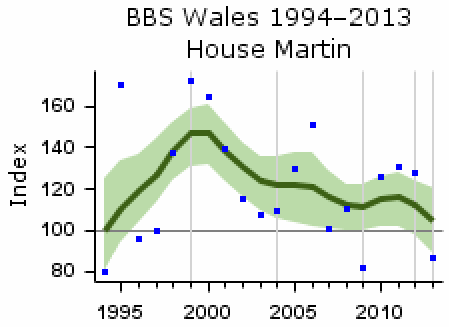
HERRING GULL (Larus argentatus)

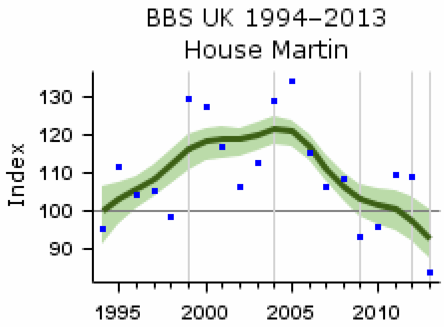




The wintering Herring Gull population in Wales has shown a steady increase since the mid-1990s, but breeding numbers have tended to fluctuate, with less of a clear, long-term pattern.

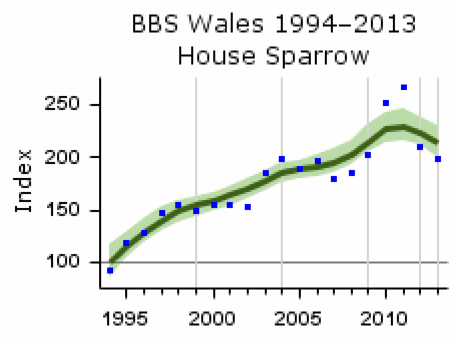
HOUSE MARTIN (Delichon urbicum)

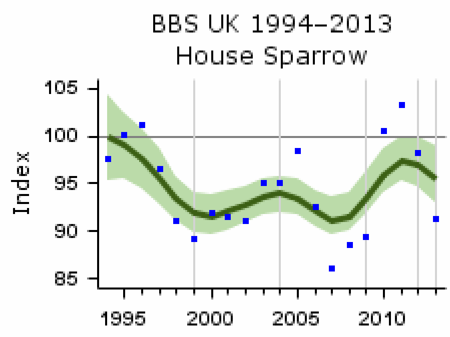




The House Martin trend in Wales has fluctuated over time, broadly in line with the wider UK pattern, but with differences in the height or depth of peaks and troughs. The patterns therefore suggest that broad-scale changes have been driven by factors common to birds at very large spatial scales, such as wintering conditions, but that factors specific to Wales may have influenced variations within these broad changes. [More detail] A specific UK House Martin survey will be run by the BTO in 2015.

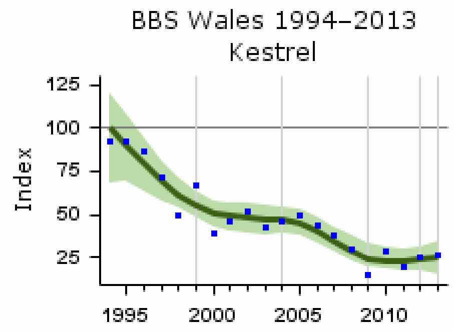
HOUSE SPARROW (Passer domesticus)

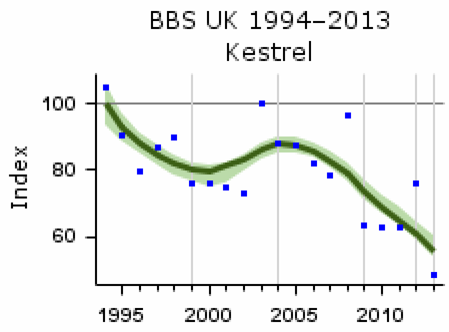




The population trend of House Sparrow in Wales is in contrast with that elsewhere in the UK, as the species has been increasing consistently through the period of BBS monitoring, although it may now be levelling off. [More detail]

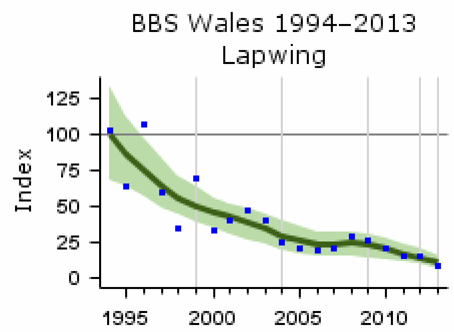
KESTREL (Falco tinninculus)

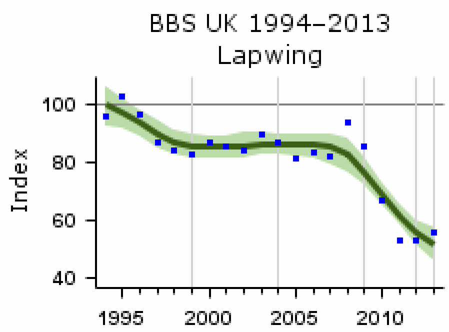




The Kestrel has shown a steady decline in Wales during the BBS period, a pattern that appears both more severe and more consistent than the decline seen at the wider UK scale. [More detail] Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares); therefore, the apparent details of the trend should be interpreted with caution.

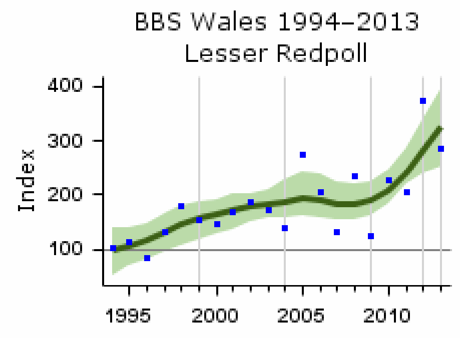
LAPWING (Vanellus vanellus)

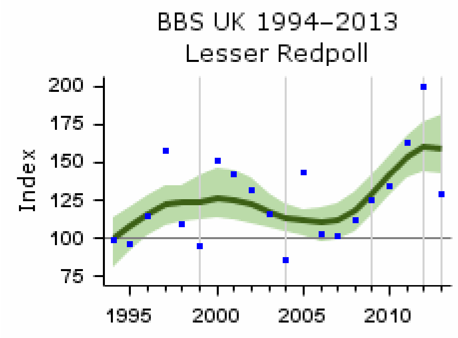




The Lapwing has shown a steady decline in Wales during the BBS period, a pattern that appears both more severe and more consistent than the decline seen at the wider UK scale. [More detail] Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares); therefore, the apparent details of the trend should be interpreted with caution.

LESSER REDPOLL (Acanthis cabaret)



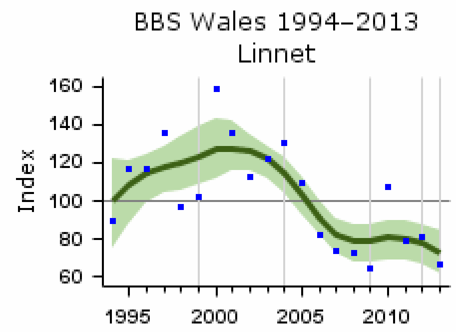


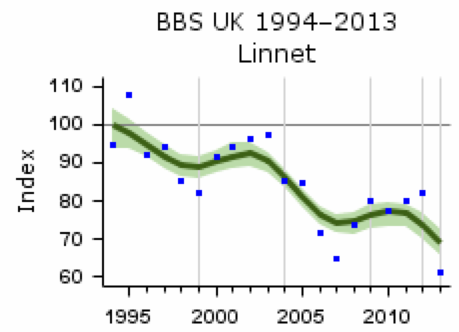
The Lesser Redpoll has shown a sustained, large increase in Wales since the inception of the BBS. This change has been larger (in percentage terms) and subject to fewer fluctuations, than the pattern across the wider UK, although the latter has also been positive overall. [More detail]

LESSER SPOTTED WOODPECKER (Dendrocopos minor)

A rather rare and localized species that can also be difficult to detect, the Lesser Spotted Woodpecker is not monitored effectively by BBS in Wales and is also too irregularly recorded in Bird Reports to allow annual trend data to be extracted. There has been a large-scale fall in abundance and loss of range across Britain and this has also been seen in Wales (Balmer et al. 2013). The species remains reasonably widespread, however, albeit at low densities (Balmer et al. 2013), which will make any putative bespoke survey activity difficult.

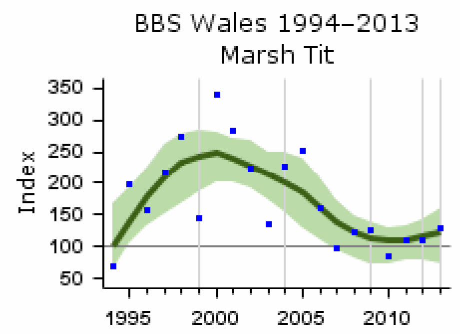
LINNET (Linaria cannabina)

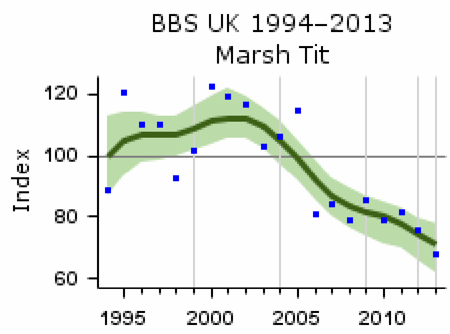




The trend for Linnet in Wales shares a clear period pf decline during the 2000s with the wider UK trends that was both followed and preceded by periods of stability, or at least less steep change. However, the details of the trend through the rest of the time series differ, suggesting that there are differences in the drivers of population change between Wales and elsewhere in the UK. [More detail]

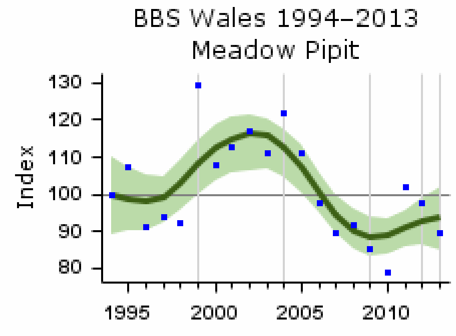
MARSH TIT (Poecile palustris)

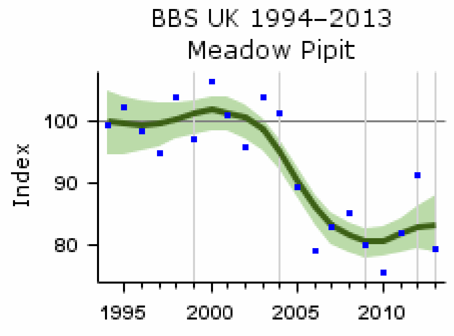




Following a long-term decline in the 1970s and 1980s, the UK Marsh Tit population has fallen further since the mid-2000s. Welsh birds have shown a similar pattern, but with larger fluctuations, and may now be relatively stable. [More detail]

MEADOW PIPIT (Anthus pratensis)



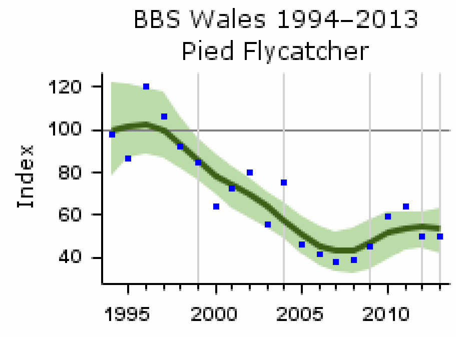


The UK Meadow Pipit population declined in the 2000s, a pattern seen also in Wales; however, this seems to have followed a transient population increase in Wales, as opposed to a period of relative stability in the wider UK. Recent population trends show signs of levelling off, or perhaps the beginning of a recovery. [More detail]

NIGHTJAR (Caprimulgus europaeus)

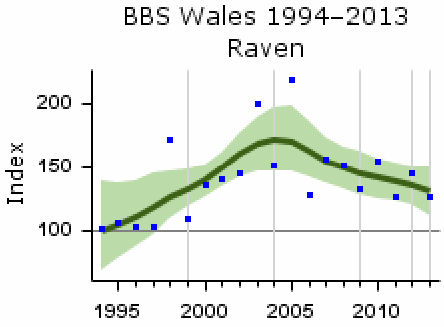
Nightjars are nocturnal habitat specialists in a rare, geographically restricted habitat (heathland and young plantation forestry), which makes them poorly suited for monitoring by the randomized, diurnal BBS and also limits casual records of the species for Bird Reports. Bird Atlas 2007-11 included specific night visits to potentially suitable habitat and recorded a general spread of the Nightjar distribution in Wales since 1990, although some locations where the species had been recorded in 1970 no longer have these birds. It is likely that there has been a general population increase, but that the suitability of some areas has changed over a timescale of several decades as forestry plantations have matured.

PIED FLYCATCHER (Ficedula hypoleuca)



The Pied Flycatcher trend in Wales is derived from a small sample of BBS squares (less than 30 squares), so the apparent details of the trend should be interpreted with caution. However, the pattern of a steep decline until the late 2000s, followed by signs of population stability, is similar to the wider UK trend, so there is no evidence that the apparent pattern of change is influenced by bias due to small sample sizes. [More detail]

RAVEN (Corvus corax)

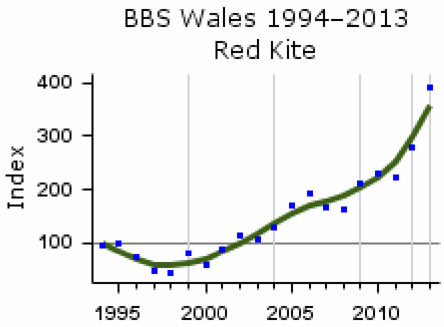


Raven populations in Wales, reflecting the wider UK population trend, have been fairly stable over time, albeit with what appears to have been a transient peak in abundance in the mid-2000s. It is likely that population changes in this species will be slow because it is long-lived and a slow breeder. [More detail]

RED GROUSE (Lagopus lagopus)

The Red Grouse remains widespread in upland Wales, although it has declined considerably since 1970 and again since 1990, leading to range losses, especially from the southern Cambrian Mountains (Balmer et al. 2013). Annual monitoring data are lacking, however, and the species is poorly recorded in Bird Reports.

RED KITE (Milvus milvus)

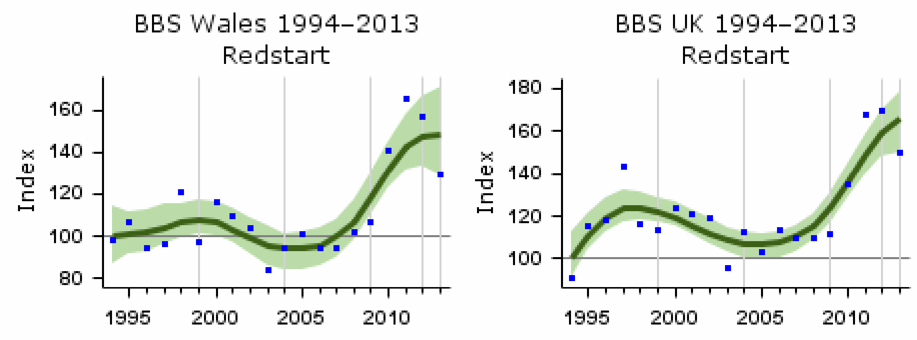


Red Kites have increased rapidly across Wales, as in the wider UK, although the changes in Wales stem from intensive conservation activity around an historical population, while those elsewhere have been seeded by large-scale re-introduction programmes. Note that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares), so the apparent details of the trend should be interpreted with caution. Moreover, there is a technical issue with calculating bootstrapped confidence intervals for this species because of very small samples and stochastically variable records in the early years. However, the long-term trend for this species is unequivocally upward, so inference about long-term population changes is unaffected. [More detail]

REDSHANK (Tringa totanus)

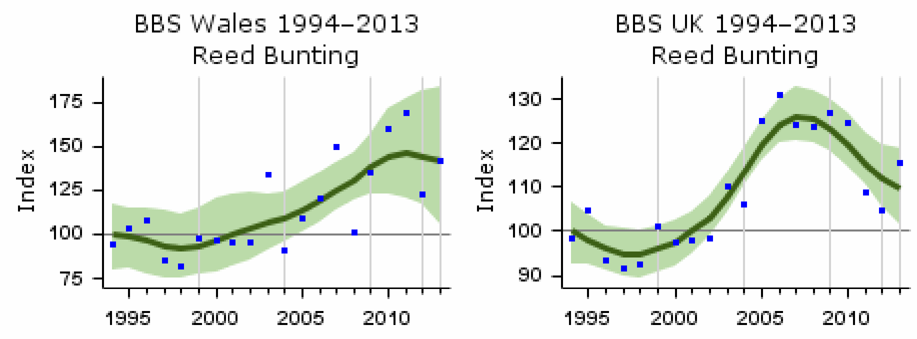
Redshank are too rare in Wales to be monitored effectively by BBS, but the UK trends from both this survey and the Waterways Breeding Bird Survey both show clear declines since the mid-1990s [More detail]. Wintering Redshank numbers have been stable in the long-term in Wales (http://www.bto.org/volunteer-surveys/webs/publications/webs-annual-report), but reflect coastal records that are likely to involve different breeding populations as well as (or completely excluding) those birds that breed in Wales, so the relevance of this pattern to breeding Welsh redshank numbers is questionable.

REDSTART (Phoenicurus phoenicurus)



Redstart populations have fluctuated over time, but have shown a sharp increase since 2006, both in Wales and in the wider UK. The drivers of this pattern are probably, therefore, common to birds from across the UK, such as conditions on the wintering grounds, although it is possible that more variable ecological or demographic relationships underlie the earlier population changes. [More detail]

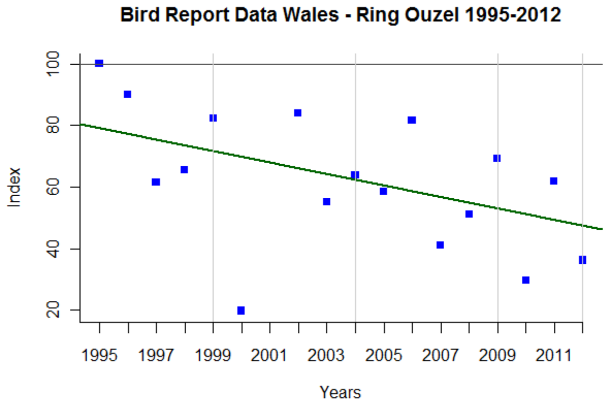
REED BUNTING (Emberiza schoeniclus)



Reed Bunting abundance has shown an increasing trend in Wales that is not dissimilar to the pattern seen in the wider UK, although the latter averages over variable regional trends. [More detail] Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares) and that the confidence intervals are broad; therefore, the details of the trend are uncertain and the apparent changes, especially short-term fluctuations, should be interpreted with caution.

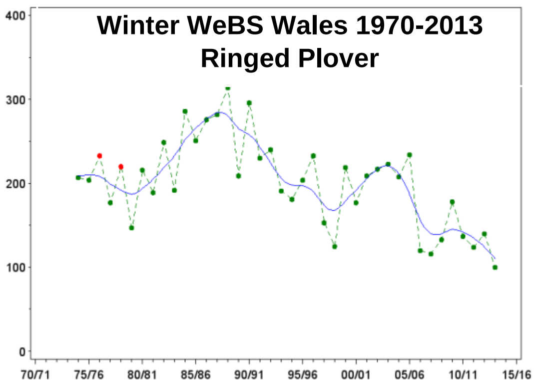
RING OUZEL (Turdus torquatus)

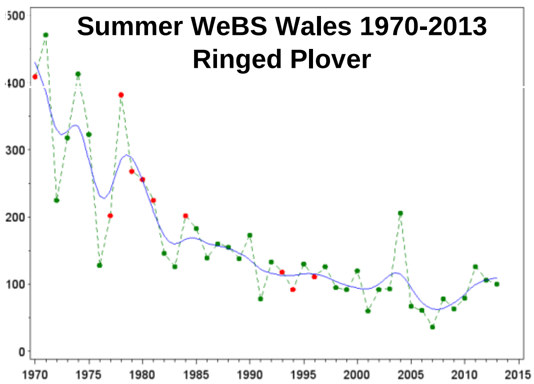
The Ring Ouzel is too rare in Wales to be monitored by BBS, but is believed to have declined in Wales, as across the UK, as reflected in range contractions since the early 1970s and late 1980s (Balmer et al. 2013). Losses since 1972 have occurred particularly from mid-Wales and the major population centres are now in Snowdonia and the Brecon Beacons. It is likely that fewer than 50 breeding pairs remain in Wales, unless significant populations are unrecorded by causal observers (Pritchard 2013).



Bird report data suggest that the Welsh Ring Ouzel population declined between 1995 and 2012. Eleven counties contributed to the trend, and whilst none of them provided entries for every year, Brecon contributed with all but one (2002), whilst Meirionnydd, Caernarfon and Montgomeryshire contributed with 10 or more years. All years were represented in the dataset, and data for six years (1999, 2003, 2006, 2008, 2009 and 2010) came from at least five counties. This species was particularly prone to entries of unspecified numbers of birds in the Welsh Bird Reports, so the trend should be interpreted with particular caution as high counts from some vice-counties were not be quantified in the dataset compiled and so the analysis assumes that trends in these counties reflected those elsewhere. This tended to be more common earlier in the time series, so the apparent decline may actually under-estimate the true changes in the population. The low, outlier index value in 2000 was due to fewer vice-counties reporting birds and low numbers being reported where counts were found.

RINGED PLOVER (Charadrius hiaticula)



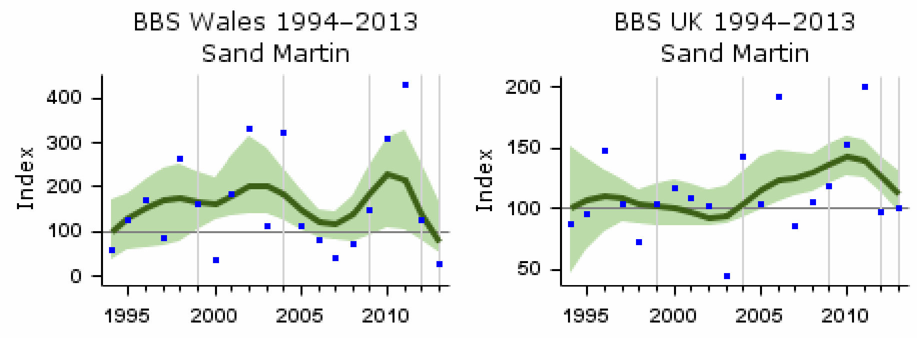


Both wintering and breeding Ringed Plover populations in Wales have tended to decline since the mid-1990s, although the winter pattern has shown both larger fluctuations and a more pronounced reduction in abundance.

ROSEATE TERN (Sterna dougalli)

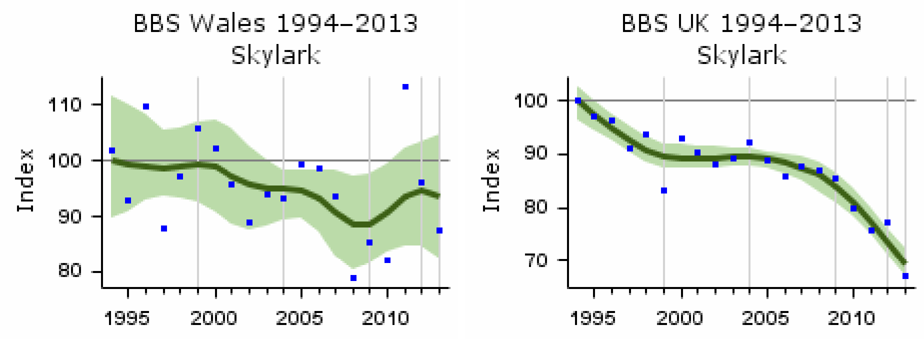
Roseate Tern has a very localized breeding distribution in the UK and has only recently been recorded on Anglesey in Wales, where the isolated records in Bird Atlas 2007-11 relate to individual birds paired with Common Terns.

SAND MARTIN (Riparia riparia)



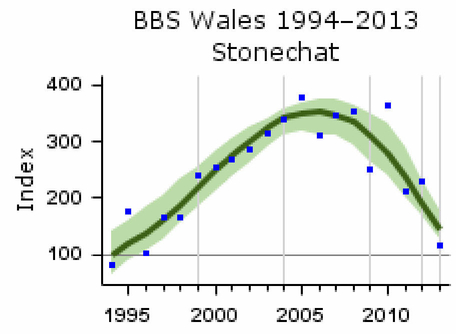
Sand Martins have shown fluctuating, but overall rather stable long-term changes in both Wales and the wider UK, although a period of decline may have begun in 2010 [More detail]. Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares) and is associated with wide confidence intervals, so the apparent details of the trend should be interpreted with caution. In addition, colonies of this species are known relocate rather rapidly in some instances, so large stochastic variations in local abundance can occur and influence apparent trends.

SKYLARK (Alauda arvensis)



The long-term decline in Skylark populations that has occurred throughout the UK has continued during the BBS period and is also seen to some extent in Wales alone, although the magnitude of change has been smaller. [More detail] It is worth noting that the confidence intervals for Wales are larger than those for the UK because the sample size is much smaller. This makes the details of the temporal trend less reliable for Wales, but it is likely that similar ecological factors underlie the changes because the gross patterns are common across the regions of the UK.

STONECHAT (Saxicola rubicola)

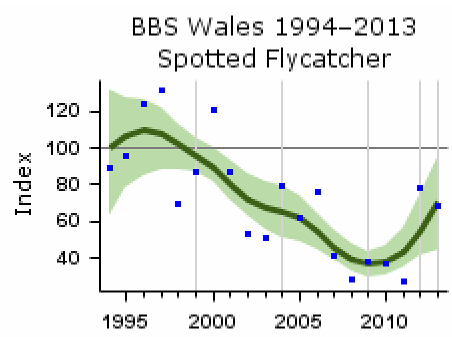


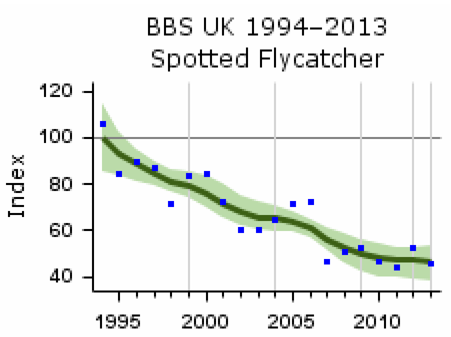
The Stonechat population trend shows a remarkable pattern of smooth, steady increase up to 2005, followed by a rapid decline, which is seen at both the UK and Wales levels. [More detail] This suggests that large, ongoing ecological changes have occurred, but the evidence on this species is limited. A recent BTO volunteer survey of chats in Wales is elucidating both current population status and relationships with habitat, and will report in 2015.

SNIPE (Gallinago gallinago)

Snipe are too rare in Wales to be monitored effectively by BBS; the survey method is also not ideally suited to the species because of its crepuscular habits, so there is likely to be more uncertainty associated with square-level counts than there is for most species. However, BBS and Waterways Breeding Bird Survey trends at the UK level show declines in Snipe abundance since 2000 (and probably earlier) [More detail], while there have been considerable losses in the breeding range in Wales in the long term (Balmer et al. 2013).

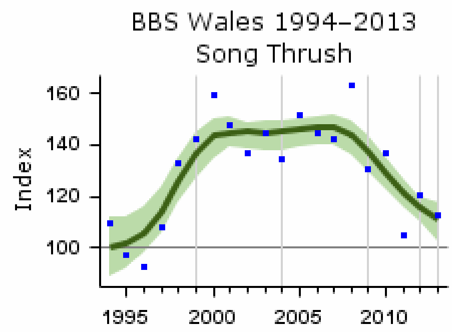
SPOTTED FLYCATCHER (Muscicapa striata)





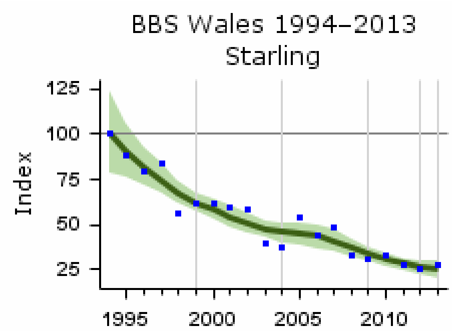
Spotted Flycatchers have been in long-term decline at the UK level and this pattern is seen in Wales alone, as well. [More detail] There is an indication, however, that the Welsh population may be in recovery, but the trend in Wales is derived from a small sample of BBS squares (fewer than 30), so this pattern should be interpreted with caution.

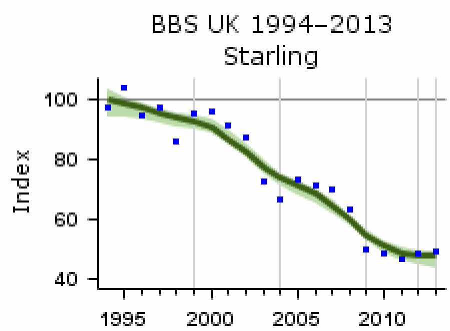
SONG THRUSH (Turdus philomelos)



Song Thrush abundance in Wales has fluctuated during the BBS period, reflecting the UK-level trend. These changes are in the context of larger, long-term declines, however. [More detail]

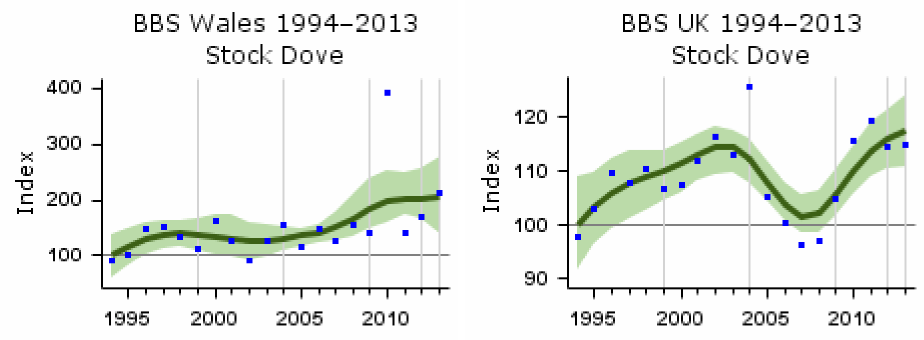
STARLING (Sturnus vulgaris)





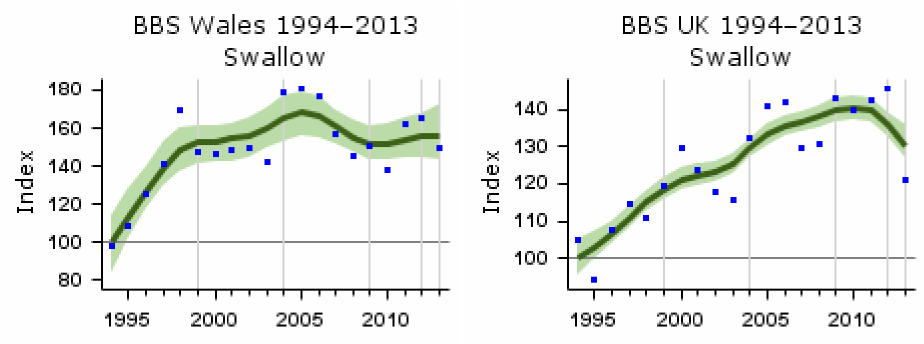
Rapid declines have occurred in breeding Starling abundance at the both the Wales and wider UK levels, although the Welsh decline may be slowing, while the wider UK one has tended to increase in rate over time, at least until 2010. [More detail] It is noteworthy that much of the public experience of Starlings involves large, roosting, winter flocks; these flocks typically consist of winter migrants from northern Europe as well as local breeding birds, so their presence and size is not closely related to UK breeding population trends.

STOCK DOVE (Columba oenas)



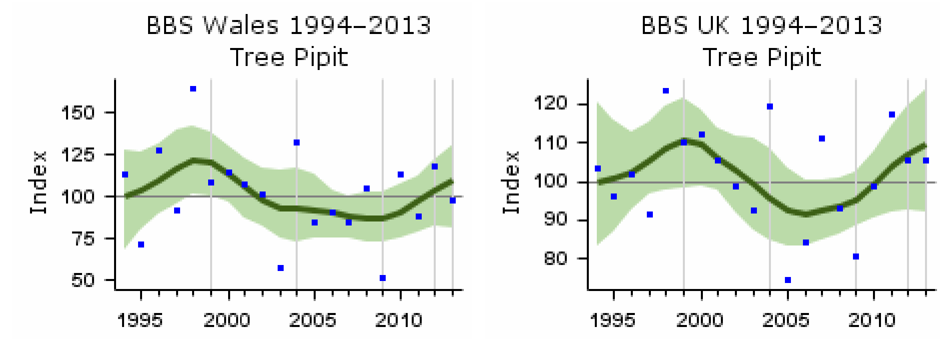
The long-term pattern in UK Stock Dove abundance is for a sustained increase following strong negative effects of organochlorine pesticides up to the early 1960s, with the increase tending to level off since the 1990s. [More detail] A general pattern for a shallow population increase during the BBS period is then apparent at both the Wales and wider UK levels, with the increase being rather smoother in Wales alone. It is likely that the increases will cease as the available habitat is saturated.

SWALLOW (Hirundo rustica)



The Swallow population in Wales has been rather stable since the late 1990s, whereas the wider UK population has tended to increase during this period, at least until 2012. [More detail] This followed a rapid increase at the beginning of the BBS period and suggests that the population may be at carrying capacity, or constrained by another factor that has shown little variation in recent years.

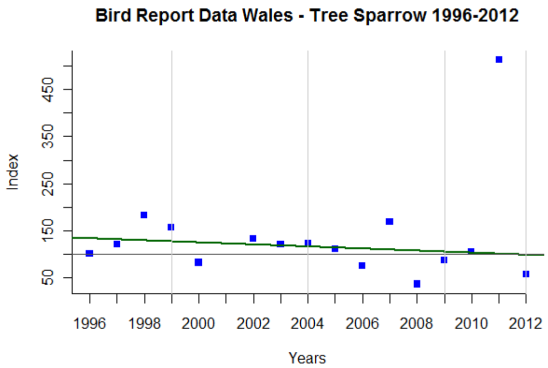
TREE PIPIT (Anthus trivialis)



Tree Pipit numbers are stable in Wales; there have some fluctuations in the trend since 1994, but no clear long-term increase or decline. The fluctuations have mirrored those in the wider UK, albeit being smaller in magnitude, suggesting that they have been driven by factors operating at large spatial scales, as opposed to specific to Wales. [More detail]

TREE SPARROW (Passer montanus)

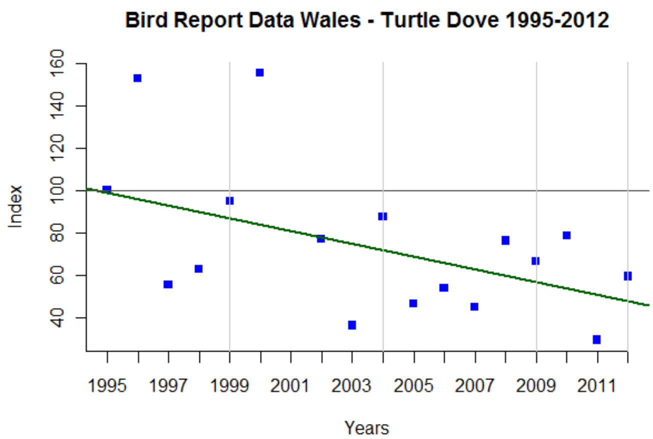
Tree Sparrows are too rare in Wales to be monitored by BBS, but are now showing a shallow, sustained increase at the UK level, following a precipitous decline before the BBS period began [More detail]. However, they are believed still to be declining in Wales. Bird Atlas 2007-11 shows range losses throughout Wales since 1972, with Tree Sparrow now being found mostly only in Clwyd and south-east Dyfed (Balmer et al. 2013).



Bird Report data for Tree Sparrow show little evidence of a clear trend between 1996 and 2012, with a pattern perhaps for a slight decline over time, although the data for the last two years in the time series are sparse, with just one (different) county with records in each year. Eleven vice-counties contributed to the trend, and whilst none of them provided records for all years, five of them (Brecon, Montgomeryshire, Pembrokeshire, Gwent, Glamorgan) contributed with at least nine years and one more, Carmarthen, with at least five; all other counties contributed with less than five years and all years, apart from 1995, were represented. [More detail]

TURTLE DOVE (Streptopelia turtur)

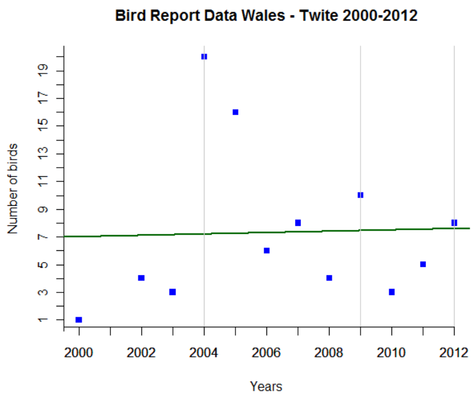
Turtle Doves are now too rare in Wales to be monitored by BBS and are declining precipitously at the UK level [More detail]. It is likely that they are declining further in Wales as well. They have also declined further in Wales, as reflected in Bird Atlas 2007-11 (Balmer et al. 2013), which showed major range losses, particularly between 1972 and 1991. After further losses before 2007, there were breeding records from a few locations along the English border only.



Bird Report data for Turtle Dove show a steep decline between 1995 and 2012, mirroring the overall decline observed in the UK overall (Baillie et al 2014). Note, however, the trend reported above may not reflect the population of breeding birds because passage birds may have contributed to the counts in some years. Ten vice counties contributed to the trend, although none with data for all years. Five vice-counties (Carmarthen, Caernarfon, Pembrokeshire, Gwent and Glamorgan) provided records for at least nine years, while a further three (Denbigh, Cardiganshire and Anglesey) contributed with at least five and the rest with four or fewer years. All years were represented in the dataset, apart from 2001, reflecting countryside access restrictions after the foot-and-mouth disease outbreak. The outlier in 2000 is due to a high count for one of only two vice-counties contributing that year.

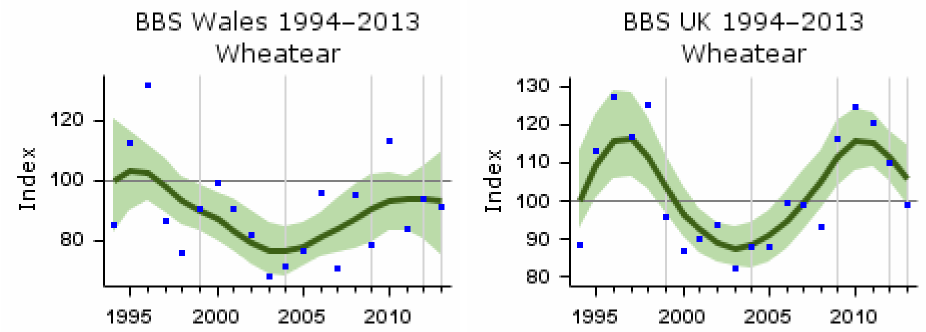
TWITE (Carduelis flavirostris)

Twite are too rare in Wales to be monitored by BBS, but are the subject of specific, periodic surveys by RSPB and others. The breeding population in Wales, although small and highly range-restricted, appears to have increased considerably in recent decades, particularly in Snowdonia and upland Clywd (Balmer et al. 2013).



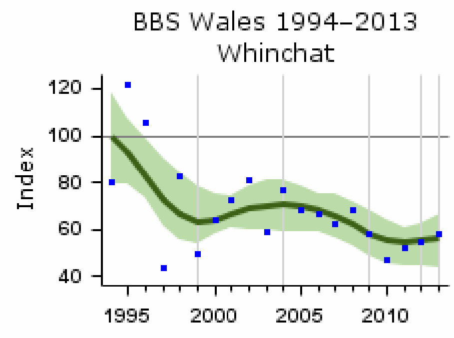
Bird report data for Twite were available from only one vice-county, Caernarfon, from 2000 to 2012 (excluding 2001); records from other counties were available from only one year, so were not included in the analysis (see Introduction). There was no clear trend in the Caernafon counts, but they were low and only a small fraction of the Welsh population.

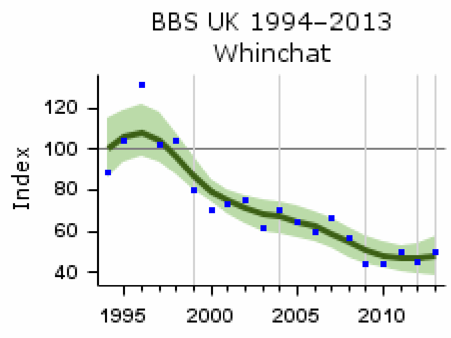
WHEATEAR (Oenanthe oenanthe)



The Welsh population of Wheatear has fluctuated during the BBS period, broadly reflecting the pattern seen across the wider UK. [More detail] This broad-scale pattern is suggestive of a role for broadly influential factors such as conditions on the wintering grounds or on migration, rather than specific to Wales, driving population change. A recent BTO volunteer survey of chats in Wales is elucidating both current population status and relationships with habitat, and will report in 2015.

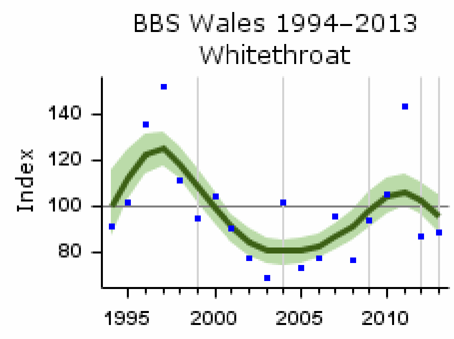
WHINCHAT (Saxicola rubetra)

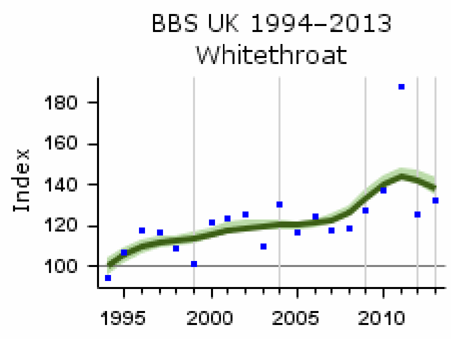




Whinchats have declined in Wales during the BBS period, although at a variable rate-of-change. The pattern is also slightly different to that seen across the wider UK (although the UK-wide population has declined even more, proportionally). [More detail] Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares); therefore, the apparent details of the trend should be interpreted with caution. A recent BTO volunteer survey of chats in Wales is elucidating both current population status and relationships with habitat, and will report in 2015.

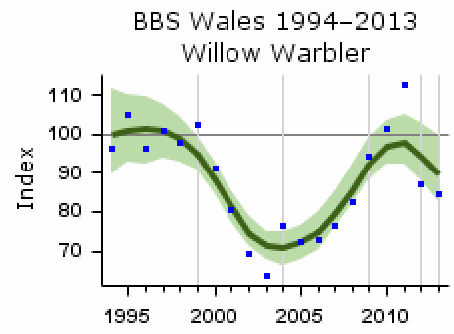
WHITETHROAT (Sylvia communis)

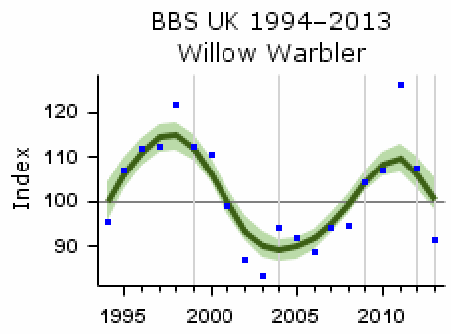




Following an historical decline in the 1970s due to weather effects on the wintering grounds, the UK-wide Whitethroat population has been slowly increasing. In Wales alone, however, the population trend has fluctuated much more. [More detail] This suggests a role for local factors driving changes that are not important for birds breeding elsewhere in the UK.

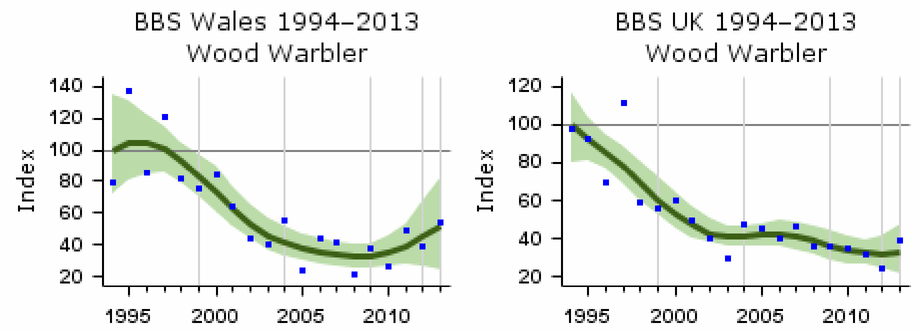
WILLOW WARBLER (Phylloscopus trochilus)





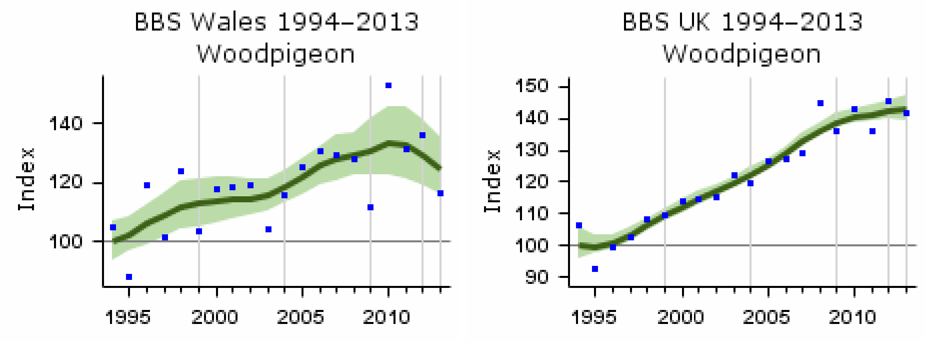
The oscillating long-term population trend of Willow Warbler in Wales is mostly similar to the wider UK trend, suggesting influences of factors that operate at large scales or that affect birds on their wintering grounds or on migration. [More detail]

WOOD WARBLER (Phylloscopus sibilatrix)



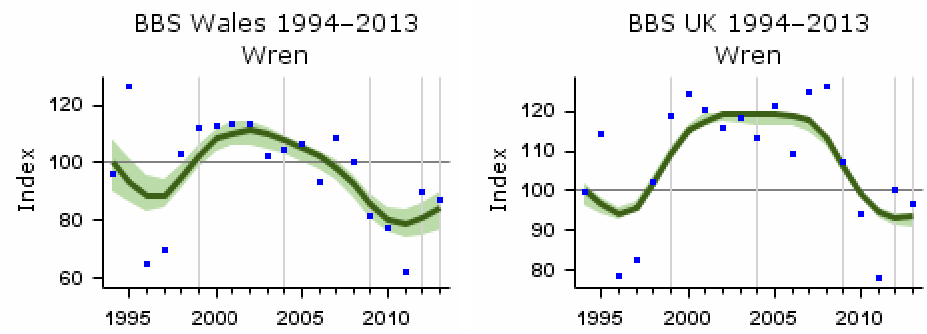
Wood Warblers have declined in Wales during the BBS period, although the trend may have turned upward since 2008. The pattern is also slightly different to that seen across the wider UK. [More detail] Note, however, that the trend in Wales is derived from a small sample of BBS squares (less than 30 squares); therefore, the apparent details of the trend should be interpreted with caution.

WOODPIGEON (Columba palumbus)



Woodpigeon numbers have increased historically across the UK and Wales is no exception. Similarly, signs of stabilization in abundance have appeared since the late 2000s, perhaps showing saturation of the available habitat or resource limitation. [More detail]

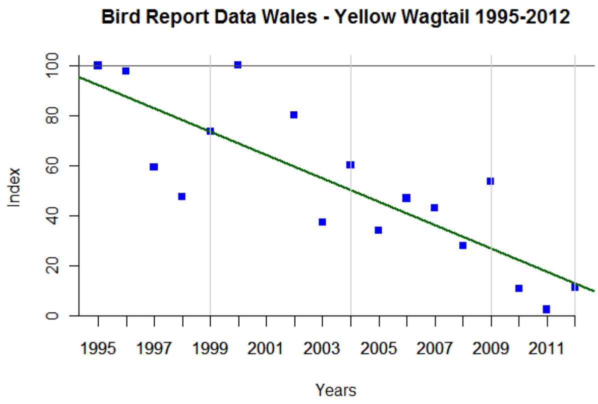
WREN (Troglodytes troglodytes)



Wren abundance is often highly variable between years because the species is vulnerable to cold winter weather. Nevertheless, long-term trends in the Welsh population are broadly similar to those in the wider UK, albeit with some evidence for a slight, long-term decline that is not apparent across the whole of the UK. [More detail]

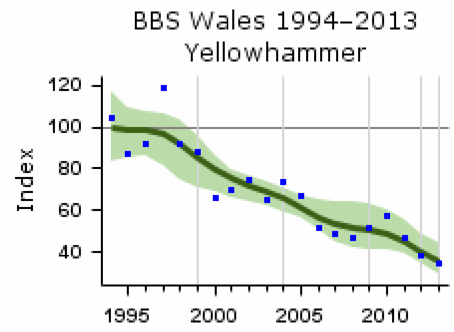
YELLOW WAGTAIL (Motacilla flava)

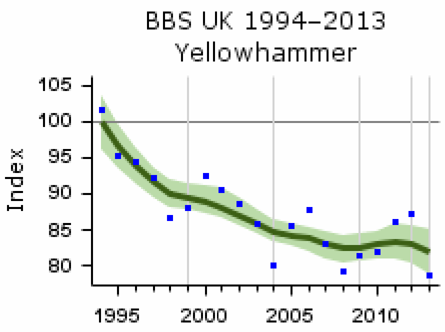
The Yellow Wagtail is now too rare in Wales to be monitored by BBS. Following a long-term decline across the UK, mirrored in marked range contractions throughout Wales since 1972, the species now breeds only in isolated locations and along the English border (Balmer et al. 2013). [More detail]



The available bird report data for Yellow Wagtail show a steep, negative trend between 1995 and 2012. Data were available for all counties, although only one, Brecon, provided a complete list for every year. One other county, former Montgomeryshire, contributed with 10 years, from 1995 to 2015, while all other counties contributed with five or fewer years. Only in 2009 reports were submitted from at least 10 counties while all other years saw records from four or fewer counties. The high index value for 2000 is due to relatively high counts in all three counties that contributed to the total for that year.

YELLOWHAMMER (*Emberiza citrinella*)





Yellowhammer abundance began to decline on farmland across the UK in the mid-1980s. Proportional declines have been steeper in Wales than elsewhere during the BBS period, with an additional recent downturn being the opposite of recent changes in England, which may be the result of agri-environment management. [More detail]

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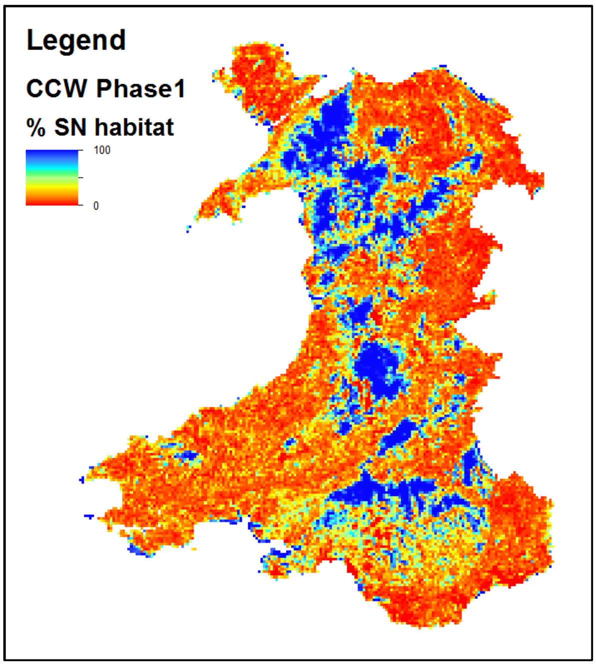
Annex 4. Matrix of population trend scores in five-year blocks derived from the trends shown in Appendix 5.3 and used to derive the population summary indicator (Section 5.2.1.3.4).

Species	Data source	Time Periods and Scores								Notes
		1994-1999	Score	2000-2004	Score	2005-2009	Score	2010-2014	Score	
Aquatic Warbler	NA									globally endangered, not in Wales
Bar-tailed Godwit	WeBS	=	1	-	0	+	1	=	1	winter - WeBS
Common Bullfinch	BBS	-	0	+	1	-	0	=	1	
Black-headed Gull	WeBS	+	1	=	1	-	0	=	1	colonial - will always be in a small number of locations; Summer WeBS
Great Bittern	NA		FALSE		FALSE		FALSE		FALSE	extinct?
Black Grouse	RSPB		FALSE		FALSE		FALSE		FALSE	surveyed regularly by RSPB
Tundra Swan	WeBS	=	1	-	0	0	FALSE	0	FALSE	winter - WeBS; population approximately zero since 02-03
Corn Bunting	NA		FALSE		FALSE		FALSE		FALSE	extinct
Corn Crake	NA		FALSE		FALSE		FALSE		FALSE	extinct
Chough	Independent data		FALSE		FALSE		FALSE		FALSE	Surveyed annually independently
Common Cuckoo	BBS	-	0	-	0	-	0	-	0	
Eurasian Curlew	BBS	-	0	-	0	=	1	-	0	
Common Scoter	WeBS	=	1	=	1	=	1	=	1	winter - WeBS; very variable with many imputed counts
Dunnock	BBS	+	1	+	1	=	1	=	1	
Dark-bellied Brent Goose	WeBS	+	1	=	1	-	0	=	1	winter - WeBS
Red-backed Shrike	NA		FALSE		FALSE		FALSE		FALSE	extinct
Common Grasshopper Warbler	BBS	-	0	+	1	=	1	-	0	14 BBS squares; UK long-term stable
Golden Plover	Reports	-	0	-	0	-	0	-	0	
Hawfinch	Reports	=	1	=	1	=	1	=	1	trend extracted from bird reports
Herring Gull	WeBS	+	1	=	1	-	0	+	1	Summer WeBS
Hen Harrier	RSPB/rare	ND	FALSE	ND	FALSE	+	1	ND	FALSE	Reliable data available for 2004-10 only
House Sparrow	BBS	+	1	+	1	=	1	-	0	

Kestrel	BBS	-	0	=	1	-	0	=	1	
Northern Lapwing	BBS	-	0	-	0	=	1	-	0	
Common Linnet	BBS	=	1	=	1	-	0	=	1	
Lesser Redpoll	BBS	+	1	=	1	=	1	+	1	23 BBS squares; UK stable during BBS period
Lesser Spotted Woodpecker	Rare		FALSE		FALSE		FALSE		FALSE	now very rare; insufficient bird report data
Marsh Tit	BBS	=	1	=	1	-	0	=	1	12 BBS squares; UK declining
European Nightjar	Nocturnal; Atlas		FALSE		FALSE		FALSE		FALSE	nocturnal
Greenland Greater White-fronted Goose	WeBS	ND	FALSE	=	1	-	0	-	0	winter - WeBS
Grey Partridge	Rare		FALSE		FALSE		FALSE		FALSE	insufficient bird report data
Pied Flycatcher	BBS	=	1	-	0	=	1	=	1	
Reed Bunting	BBS	=	1	=	1	+	1	=	1	
Red Grouse	Rare		FALSE		FALSE		FALSE		FALSE	insufficient bird report data
Ringed Plover	WeBS	=	1	=	1	-	0	=	1	
Ring Ouzel	Reports	-	0	-	0	-	0	-	0	trend extracted from bird reports
Roseate Tern	Rare		FALSE		FALSE		FALSE		FALSE	very rare, only odd breeding records
Sky Lark	BBS	=	1	=	1	-	0	=	1	
Spotted Flycatcher	BBS	=	1	-	0	-	0	+	1	
Common Starling	BBS	-	0	-	0	-	0	-	0	
Song Thrush	BBS	+	1	=	1	=	1	+	1	
European Turtle Dove	Reports	-	0	-	0	-	0	-	0	now very rare
Tree Pipit	BBS	=	1	=	1	=	1	=	1	
Eurasian Tree Sparrow	Reports	=	1	=	1	=	1	=	1	now very rare
Twite	Reports	=	1	=	1	=	1	=	1	surveyed regularly by RSPB; trend extracted from bird reports here
Wood Lark	NA		FALSE		FALSE		FALSE		FALSE	extinct
Wood Warbler	BBS	=	1	-	0	=	1	=	1	
Willow Tit	Rare		FALSE		FALSE		FALSE		FALSE	now very rare; insufficient bird report data
Yellowhammer	BBS	=	1	-	0	-	0	-	0	
Yellow Wagtail	Reports	-	0	-	0	-	0	-	0	now rare in Wales, only near English border

Appendix 5.4: Comparison of Phase 1 habitat map and satellite Land Cover Map

A comparison exercise was carried out to determine whether the CCW Phase 1 dataset and the LCM2007 data would give similar estimates of the proportion of semi-natural habitat. Maps of % SN habitat for each 1 km^2 across Wales, were produced using both datasets (Figure 3). Overall the maps show a similar spatial pattern, but some differences are visible. A difference map was also produced to highlight the spatial dependence in the agreement between the two datasets.



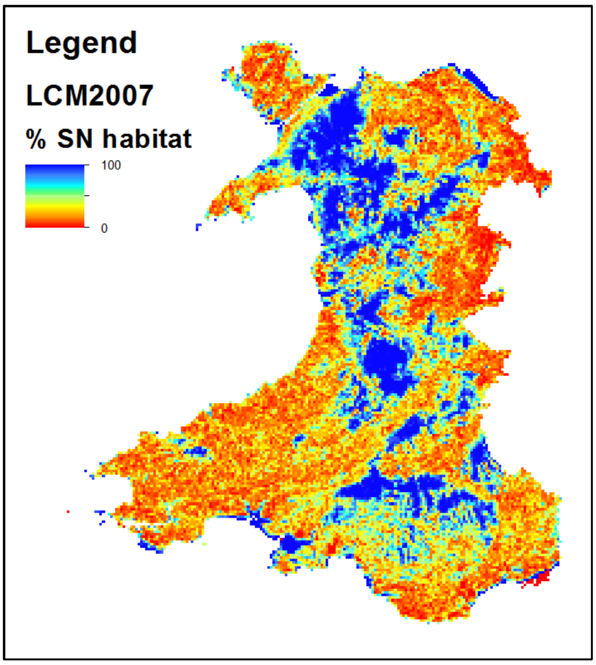


Figure 3. *Map of proportion of semi-natural habitat (%) estimated using CCW Phase 1 data (left) and LCM2007 (right).*

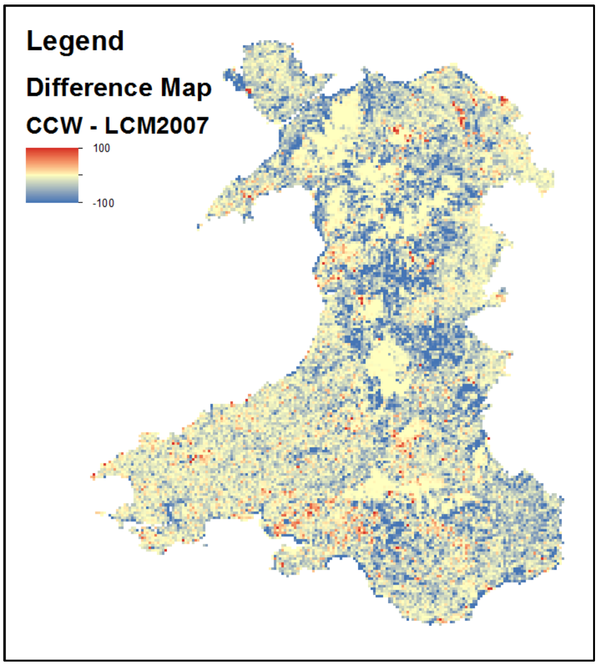


Figure 4. *Map to show the percentage difference between the proportion of semi-natural habitat (PSN) estimated using CCW Phase 1 data and that estimated using LCM2007. Red areas show where CCW Phase 1 had a higher PSN estimate than LCM2007 and blue areas show where LCM2007 gave a higher PSN estimate than CCW Phase 1.*

Scatter plots of the relationship between the % SN habitat estimates from the two datasets showed a good level of agreement, with most points being distributed around the 1:1 line (Figure 5). However, LCM2007 had a tendency to give a higher % SN habitat estimate than CCW Phase 1. The scatter plots for each of the case study areas exhibited a similar pattern (Figure 6).

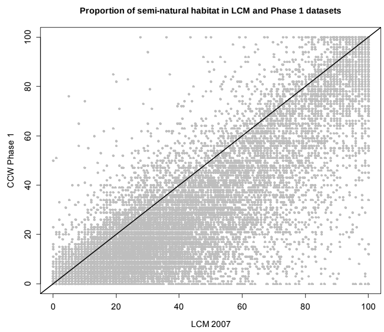


Figure 5. *Scatter plots showing the proportion of semi-natural habitat (%) estimated from LCM2007 and CCW Phase 1 datasets, for each 1km² across Wales.*

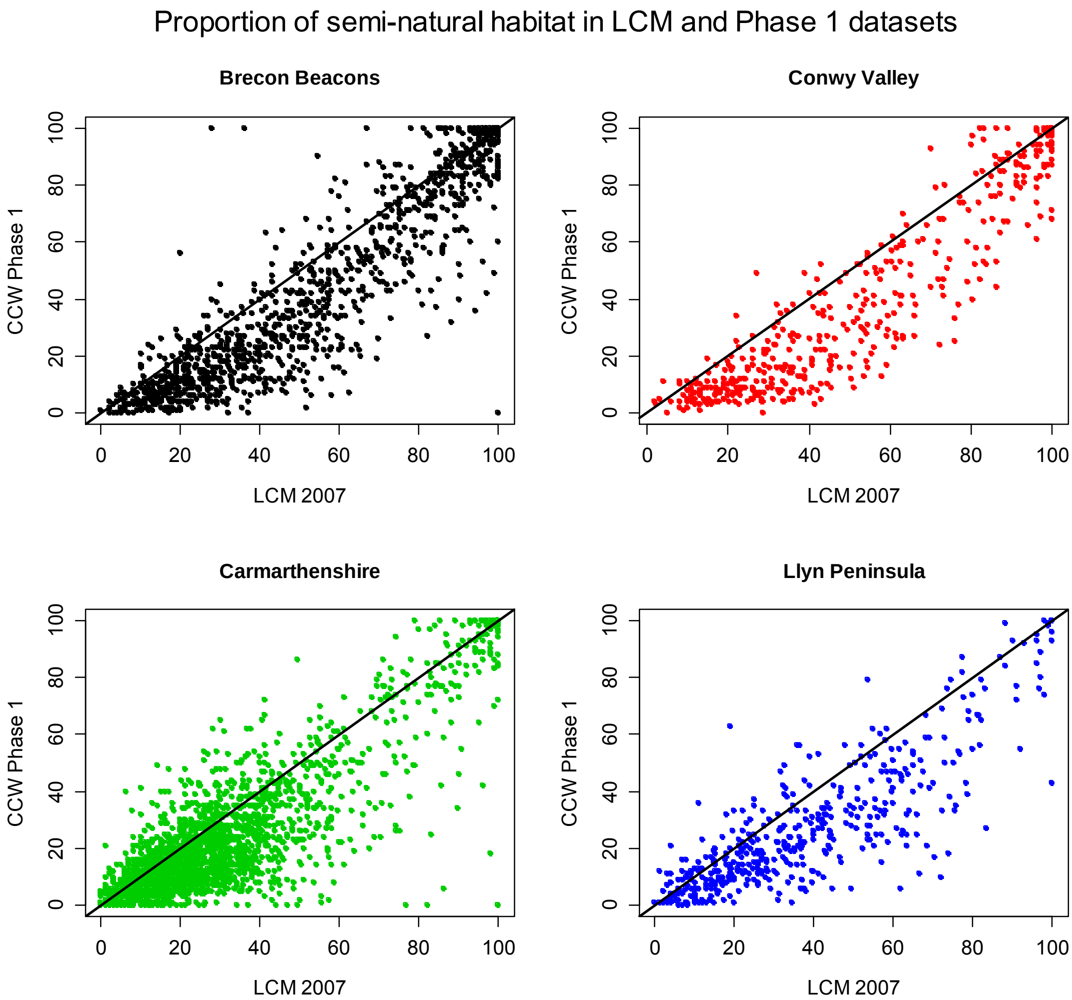


Figure 6. *Scatter plots showing the proportion of semi-natural habitat (%) estimated from LCM2007 and CCW Phase 1 datasets, for each 1km², for the four case study areas.*

Appendix 5.5: Habitats used in calculating semi-natural or modified land cover

Table 21. *List of LCM2007 classes categorised as either semi-natural or modified land cover.*

LCM2007 Class		Semi-natural or modified
1	Broadleaved woodland	Semi-natural
2	Coniferous Woodland	Modified
3	Arable and Horticulture	Modified
4	Improved Grassland	Modified
5	Rough grassland	Semi-natural
6	Neutral Grassland	Semi-natural
7	Calcareous Grassland	Semi-natural
8	Acid grassland	Semi-natural
9	Fen, Marsh and Swamp	Semi-natural
10	Heather	Semi-natural
11	Heather grassland	Semi-natural
12	Bog	Semi-natural
13	Montane Habitats	Semi-natural
14	Inland Rock	Semi-natural
15	Saltwater	Semi-natural
16	Freshwater	Semi-natural
17	Supra-littoral Rock	Semi-natural
18	Supra-littoral Sediment	Semi-natural
19	Littoral Rock	Semi-natural
20	Littoral sediment	Semi-natural
21	Saltmarsh	Semi-natural
22	Suburban	Modified
23	Urban	Modified

Appendix 5.6: Calculating Monad (1km square) species pools for vascular plants

To determine the monad species pools we first extracted records from the BSBI plant database between 1970 and 2013. We ran Frescalo to identify species pools at the hectad scale while accounting for recorder effort (corrected hectad pools). We then looped through each monad and identified a set of "missing species". These were determined as those species present in the corrected (frescalo) species pool for the associated hectad but missing from the monad in question. For each missing species, we used a Bernoulli coin flip to estimate presence (1) or absence (0) within the monad. The coin flip was weighted so that the probability of being present (1) was a combination of the proportion of suitable habitat and probability of presence at the hectad level. The proportion of suitable habitat was estimated as the cumulative proportions of all suitable habitat types (LCM 2007) given the species habitat associations in plantatt. This was multiplied by the probability of presence at the hectad level, which was estimated from frescalo (bounded between 1 and 0, with 1 being 100% present).

Appendix 5.7: Characterising soils of national importance in Wales

In Scotland work has been undertaken to identify, soils of national conservation importance (Towers et al., 2005; 2008); soils are assessed based on conservation and functional importance. Abundance was one of the criteria used (Towers et al., 2005), and they tested 3 methods of assessing abundance:

a) *Soil landscape method: All 580 Soil Map Units were allocated to a 'soil landscape' type, based on the predominant Major Soil Sub-Group and their associated soil types within different landscapes. In this way, Soil Map Units with similar assemblages of soil types (based on the dominant and secondary Major Soil Sub-Groups) were grouped together, termed 'Aggregated Soil Map Units'. This method therefore does not assess the rarity of individual Major Soil Sub-Groups, but rather the rarity of different soil assemblages.*
b) *Dominant soil sub-group method: Each soil map unit is allocated to the predominant Major Soil Sub-Group within it. In some Soil Map Units, the dominant Major Soil Sub-Group comprises 100 of the unit, whereas in many of the complex units, it can be as low as 40.*
c) *Estimated area of soil series method: The percentage cover of each Major Soil Sub-Group within each Soil Map Unit is assessed so that the total area of each map unit is apportioned to its component Major Soil Sub-Group based on this percentage. The total area of each Major Soil Sub-Group is then calculated by summing the contribution from each Soil Map Unit.*

They used the first method, but commented that all three methods gave similar results. In later work they used an alternative method fixing the value for rarity, rather than trying to define an inflexion point on the frequency distribution they aggregated soil map units and defined as rare those whose area, when summed, occupied less than 5 of the study area.

Appendix 5.8: Spatial modelling of plant species occurrence at multiple scales

Pete Henrys[1], Janine Illian[2] and Charlotte Todd-Jones[2]

[1] CEH Lancaster, [2] Department of Statistics, University of StAndrews

The ultimate aim of this work is to model and estimate plant species occurrence probabilities over the whole of Wales using the species data recorded from the GMEP vegetation plots. We do this by assuming that these probabilities are a realisation of a Gaussian random field – essentially a random spatial process covering the wholes of Wales from which any species occurrence data is a realisation. Modelling in this way ensures that we preserve the spatial properties inherent in the species data.

We have two key data sets available from which to build the model. The first is the vegetation data recorded as part of the main GMEP field survey in the vegetation "X" plots. This detailed, quality assured quadrat data consists of species presence absence data due to the census approach of monitoring the full quadrat. Additional data from the GMEP survey, such as soil pH and land cover, also allows us to include predictor variables in our model for a more detailed assessment of spatial heterogeneity. The second species data set available is the volunteer collected data from the BSBI (Botanical society of the British Isles) coordinated and stored by the BRC (Biological Records Centre). This data has complete spatial coverage of Wales at 10km, but has presence only data and suffers from uneven recorder effort. As the two species records contain complimentary species, we can assume that they are independent realisations of the same underlying process, albeit at different scales and hence with different variance. This is the Gaussian random field we wish to estimate.
The initial model we have developed was therefore a simple latent Gaussian model that contains a Gaussian Random field to account for spatial autocorrelation in the response and additional variance components corresponding to the differing scales of the species data: GMEP field data 1km square and the BRC 10km square. Specifically, the Gaussian field is a Matèrn field, approximated by a solution to an SPDE (stochastic partial differential equation) as described in Lindgren et al. (2011). This approximation is based on a constrained Delauney triangulation (the "mesh") of the spatial domain of interest. The model is then fitted using INLA (integrated nested Laplace approximation, Rue et al., 2009) for computational efficiency.

We model the GMEP vegetation data, including the wider 10km presence only species pool data from BRC as a spatial predictor. As our species data from the GMEP squares is presence/absence, the model assumes a binomial response, where measurements are assumed to be independent conditional on the latent field. The latent field contains both the Matèrn field and spatial covariates (currently pH, BRC species pool data and land cover, but factors and other covariates can be easily added).
Extensions will include:

- accounting for the uncertainty in the spatial predictors;
- accounting for varying effort in the species pool data;
- including other ecological predictors associated with the climatic and other habitat preferences of the species.

Initial Runs

Initial model runs show that the structure of the model works well and that computational efficiency is optimised by use of the SPDE and INLA approaches. The model described above has currently been run for one species (*Agrostis capillaris*) using the limited range of spatial covariates (Figure 7). We intend to run the current model on more species before extending the set of predictors used to estimate relationships and the species' spatial distribution.

The map below shows the estimated surface of occurrence probabilities for *Agrostis capillaris* and the table shows the relationship between the GMEP vegetation data modelled and the spatial predictors. Note that these are both preliminary outputs to show the model running rather than conclusive results.

The mapped species probabilities are plotted at $1km^2$ resolution, this being the finest resolution across all the predictor variables. Although the model was built at the $200m^2$ plot level, $1km^2$ probabilities were obtained by repeatedly sampling from the fitted model: within each 1km cell, 5000 estimates of species probability were obtained representing the 5000 $200m^2$ plots within the 1km square. From these 5000 probabilities a realized set of 5000 species presence/absence records were estimated. The proportion of presences was then taken as the species occurrence probability within the 1km square.

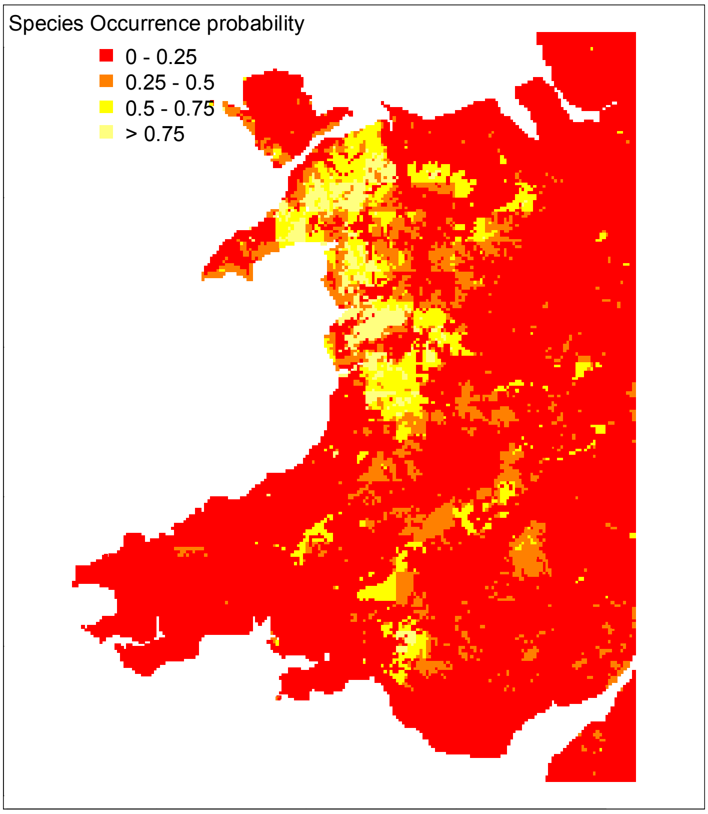


Figure 7: *Map showing the estimated probability of Agrostis capillaris occurring in each 1km grid cell, based on the fitted model.*

	Coefficient Estimates		
	Lower	Median	Upper
Intercept	-62.21	-26.38	14.62
ph	-4.10	0.29	5.37
BRC 10km Species Pool	0.04	3.71	9.05
Broadleaved Woodland	-40.65	-1.46	23.85
Coniferous Woodland	-6.86	21.34	45.89
Improved Grassland	-126.06	-60.39	-19.28
Rough Grassland	-53.80	-11.10	12.68
Neutral Grassland	-80.39	-40.24	-10.66
Calcareous Grassland	-12.99	17.37	40.84
Fen, Marsh and Swamp	-83.43	-12.38	30.55
Heather	-12.20	23.77	49.83
Heather Grassland	-14.65	14.53	37.48
Bog	-3.72	28.20	54.29
Supra-littoral Rock	-48.91	9.83	98.14
Supra-littoral sediment	-18.10	22.22	64.15
Saltmarsh	-89.78	-40.16	-11.72
Urban	-41.49	25.67	111.82

Table 22: *Estimated coefficients (median) together with credible intervals (lower and upper) for each parameter in the fitted model. Highlighted rows show significant variables.*

From the modelling approach taken it is also possible to extract the mean and standard deviation of the fitted random spatial field and plot across Wales to visualise the spatial correlation and uncertainty in the data. This spatial field shows where we are most uncertain in the probability estimates, either because of lack of data or weak covariate relationships and as such is a valuable output from the analysis to draw robust conclusions.

Figure 8 shows the standard deviation in the fitted random field and the lowest variation (blue spots) occur where we have a high number of observations and strong covariate relationships as defined in Table 22. It is clear that this uncertainty varies in space and clearly demonstrates the advantage of including this form of spatial heterogeneity in the model.

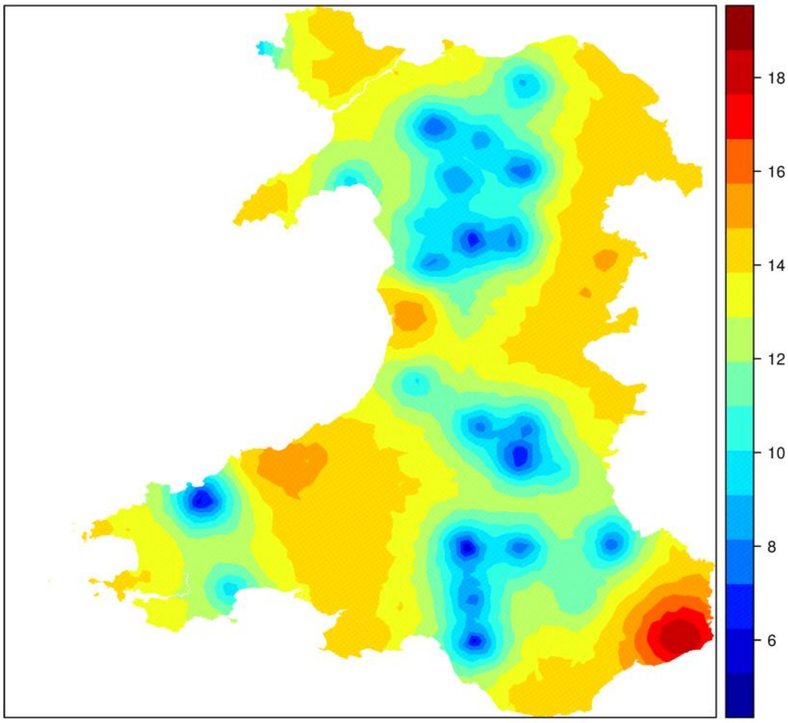


Figure 8: Estimates standard deviation of the fitted spatial random field in the model. The legend is in standard deviations and as such has no units. Areas with low uncertainty (deep blue hotspots) correspond to areas with a high number of observations and strong covariate relationships.

Conclusions

Although there have been previous attempts to model and map species occurrence probabilities over large spatial areas, few have regarded the data in its true spatial form and hence account for the differing sources of variation present in the data. The modelling approach adopted here has taken account of spatial autocorrelation present in the data and the spatial un-evenness in the observation locations. This is often ignored when building species distribution models as the focus is often on covariate relationships, but including this is key to ensure that inference made from the model and predictions based on the model are robust. The INLA approach described, not only accounts for this spatial correlation but does so in a fast efficient way meaning that multiple species runs, which have previously been computationally infeasible, are possible.

The flexible model has also allowed us to work at various spatial scales. We have included key random effects such that 10km BRC data and 200m GMEP data can be combined into the same model and we have utilised the Bayesian nature of the model to draw realisations and produce 1km predictions from a model built using 200m2 plot data. This unique approach has ensure we have maximised the use of all available data.

Further extension to this modelling technique such as those previously mentioned as well as incorporating a temporal element to account for changes over time, will enable us to realise a uniquely robust, informative, novel and scale-variant species modelling capability.

References:

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Appendix 5.9: Future developments for the Wales-only Priority Invertebrate Species indicator

Bayesian vs WSS approach

The Priority Invertebrate Species Indictaor is an example of the "*trends in occurrence indicators*". These are based on semi-structured biological records that were collected by a vast network of volunteers. Such data tend to contain various forms of noise and bias that can inhibit their use in trend estimation (Tingley & Beissinger, 2009; Hassall & Thompson, 2010; (Isaac *et al.*, 2014b). Recent analytical developments have highlighted several approaches that produce robust trend estimates while accounting for such bias (Isaac *et al.*, 2014b). The priority species indicator was based on the "well-sampled sites" mixed effects modelling approach of Roy *et al.* (2012) and Isaac *et al.* (2014a). A key aspect of this approach is the two-stage filtering process that ensure the models are only based on a "well-sampled" subset of the data. First, those visits (unique combination of site and date) with species lists shorter than the median list length recorded across all sites were excluded, then sites with less than 3 years of data (records) were removed. For each species, a generalised linear mixed effects model with binomial error structure was fitted to the well-sampled data subset, with year as the fixed effect and site as a random effect (Roy *et al.,* 2012). The yearly fitted occupancy values were extracted from the models and formed the annual occupancy index for each species. These species-specific annual occupancy estimates were then combined to form the annual priority species indicator that was calculated as the geometric mean across all species, each year. Confidence intervals surrounding the geometric mean were estimated by bootstrapping (Buckland *et al.*, 2005). A key assumption of the well-sampled sites model is that species' detectability has not changed over time. However, in many cases this assumption is not met, for example, new survey techniques (e.g. the invention bat detectors), the publication of new identification keys, variation in the time of year of survey, or focussing recording onto targeted species (e.g. the harlequin ladybird survey - http://www.harlequin-survey.org/) can all alter detectability.

Recent studies have highlighted the value of Bayesian occupancy models for estimating species occurrence in the presence of imperfect detection (van Strien *et al.*, 2013; Isaac *et al.*, 2014). This approach uses two hierarchically coupled sub-models, one, the state model, governs the true presence/absence of a species at a site in a given year, the second, the observation model, governs the probably of detecting that species given its presence or absence, and is therefore conditional on the state model (Equation 1). For each site year combination the model estimates presence or absence for the species in question (Z_{it}), which is linked to the observed data (y_{jtv}), given variation in detection probability (p_{jtv}). These Z_{it} values are then combined to create an annual estimate of the proportion of occupied sites.

Equation 1: The Bayesian occupancy model used to estimate annual proportion of occupied sites.

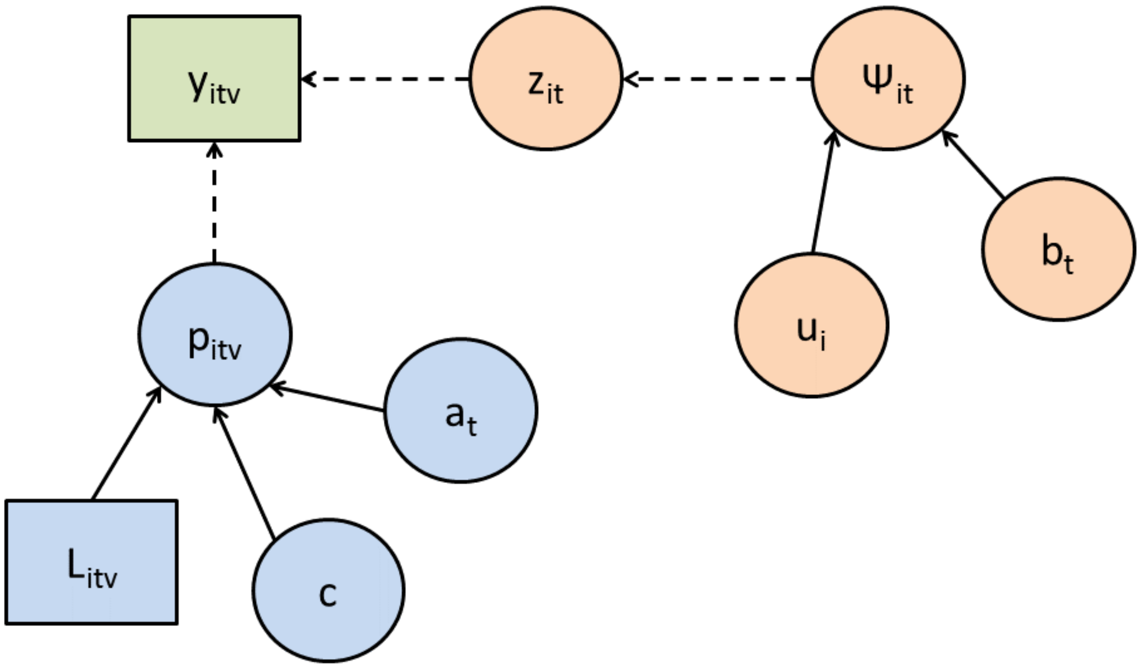
State model - $z_{jt} \sim \text{Bernoulli}(\psi_{jt})$; $\text{logit}(\psi_{jt}) = b_t + u_j$

Observation model - $y_{jtv} | z_{jt} \sim \text{Bernoulli}(z_{jt} * p_{jtv})$; $\text{logit}(p_{jtv}) = a_t + c.\log(L_{jtv})$

Z_{it} = True occupancy of site (i) in year (t). Can be a 1 or 0, present or absent.
ψ_{jt} = The probability that site (i) is occupied in year (t)
b_t = Year effect (categorical)
u_j = Site effect (categorical)
y_{jtv} = Observed presence/absence at site (i) at year (t) on visit (v)
p_{jtv} = The probability of detection at site (i) at year (t) on visit (v), conditional on Z_{it} that is the species true presence or absence.

a_t = Year level random effect (categorical)
L_{jtv} = List length at site (i) in year (t) on visit (v)
c = Change in the log-odds of detectability associated with an increasing list length by a factor of *e.*

Figure 9 *Directed acyclic graph illustrating the occupancy model structure. Orange shading represents the state model, blue shading represents the observation model, and the green box represents the observed data.*



The occupancy model approach requires repeated visits within a closure period (a year, in this case) from which the detection probability is estimated following capture-recapture theory (MacKenzie, 2006; van Strien *et al.*, 2013). Detectability is also informed by the number of species recorded on a given visit (L_{itv}), a proxy for recorder effort.

Where the WSS indicator was based on fitted values, here we use the species-specific annual occupancy estimates. Again the annual index for the priority species indicator can be calculated as the geometric mean of these annual occupancy estimates across all species. Each species is given equal weighting when calculating the geometric mean and the 95% confidence intervals can be calculated via bootstrapping (Buckland *et al.*, 2005). As the WSS indicator was based on fitted values from linear models, the 95% confidence intervals tend to increase overtime reflecting the gradual divergence of the species-specific trend lines from the fixed origin of 100 in the initial year. In contrast, the species-specific annual occupancy estimates used in the Bayesian indicator are not restricted to follow a linear pattern, and as a result the 95% CIs are not expected to follow the temporal increasing pattern as seen in the WSS indicator. An additional benefit of the occupancy model approach is that results for past years will not be affected by the addition of data for future years, which is not the case for the WSS model.

Modelling the impact of covariates including Glastir

The indicators were developed as a metric of the ongoing trends in priority species. An area for future study would be to further develop the indicator to monitor the effectiveness of conservation strategies aimed at halting biodiversity loss. Such a development may be applied to the Welsh indicator with the aim of improving our understanding of the impact of Tir Gofal on priority species. An initial approach would be to run the models on separate subsets of the data, one subset consisting of 1km grid squares that have received targeted conservation management, while the other subset consists of those without. Each subset of data would be represented by its own indicator (inter-annual variation in occupancy), and when plotted together would illustrate the difference in the average trend across priority species in regions with and without targeted conservation management. There are several limitations of this approach, firstly, variation in the conservation management approach, and in the time-frame of their implication will create noise in this metric. For example, we are less likely to detect the impact of conservation management after just one year, compared to several years of implementation. Furthermore, species' responses to conservation management is likely to lag behind its implementation. Additionally, species will respond in a variety of ways to conservation management (e.g. some may benefit and increase while others decline) such variation would be missed in a composite indicator. Finally, separating the impact of conservation management on the indicator from the impact of inter-annual variation in environmental factors (such as weather) presents a challenge that is likely to be amplified when using coarser resolution data.

An alternative approach would be to include a conservation management covariate into the occupancy model (see *extensions to the model* section of MacKenzie *et al.* 2002). In its simplest form, this would be the addition of a binary explanatory variable (*managed* vs *non-managed*) to the state model, therefore, ψ_{jt} (the probability that site *i* is occupied in time *t*) would be related to a site-year conservation management term (1/0). Rather than being a simple binary variable (*managed* vs *non-managed*), this management variable could take a number of other forms. For example, it could be a categorical variable based on the different conservation management options (e.g. the various agri-environment scheme options), or alternatively it could be a continuous variable based on the proportion of land cover within the grid cell devoted to conservation management. By adding a management term into the occupancy model we would produce a coefficient for the impact of management on the probability of occupancy for each species. These values could then be combined (in a similar way to the species-specific annual occupancy estimates for the indicator) to give a single value for impact of conservation management across all priority species. A key advantage of this approach is that the flexibility of the model and that the models estimate the impact of management on a site-year basis means that the majority of the limitations listed in the paragraph above do not apply.

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Appendix 5.10: Biodiversity - data portal entries

Headline question: What are the long term trends in biodiversity in Wales?

Priority Species Indicator for Wales

Target: *Biodiversity*

Question type: *Long term trends*

Question: *What are the long-term trends in occupancy of well-recorded priority invertebrate species in Wales?*

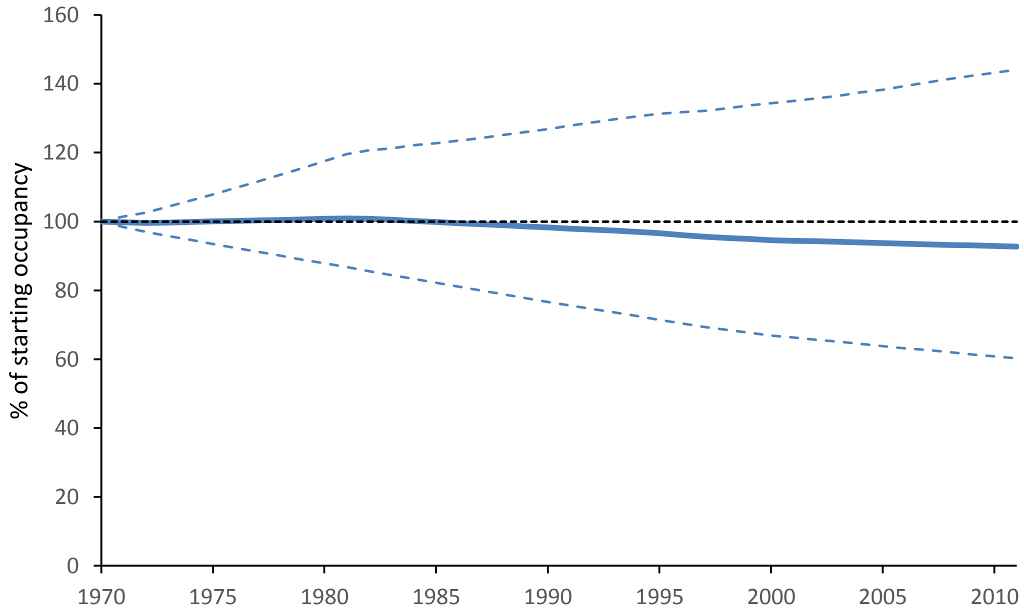
Background to question:

Given the many threats to biodiversity (e.g. habitat loss, invasive species, climate change, etc.) and the need to report on progress towards Strategic Goal D "*Enhance the benefits to all from biodiversity and ecosystem services*" of the Aichi Targets from the Convention on Biological Diversity (http://www.cbd.int/sp/targets/), there is a need to develop an accurate metric of biodiversity status. Temporal trends in such a metric can be used to monitor long-term change, and can assess the effectiveness of conservation strategies aimed at halting biodiversity loss. Here we use an indicator that utilises opportunistic biological records to examine the long-term trends in priority invertebrate species in Wales. The derivation of the indicator mirrors the approach applied at UK level (http://jncc.defra.gov.uk/page-6850) hence the two are directly comparable. Species covered by other established recording schemes – birds, bats, plants - or where reliable data does not exist for the time period were excluded.

Evidence:

The priority invertebrate species indicator (Figure 1) illustrates the change in frequency of occurrence of well-recorded priority species in Wales between 1970 and 2010. The indicator was created by combining the annual frequency of occurrence estimates of 87 species, the majority of which are moths (81 moths, 1 dragonfly and 6 bee species). The indicator shows a marginal decline across all species, however the 95% confidence intervals surrounding the trend are large and span zero. Consequently we cannot decisively say that the trend across priority species is anything other than stable.

Figure 1. Change in the frequency of occurrence of priority invertebrate species in Wales between 1970 and 2011. The dashed lines represent 95% confidence intervals for mean annual occupancy estimate.



Data:
We provide the annual index values and their associated 95% confidence intervals (Table 1). The annual index is the geometric mean of the annual frequency of occurrence estimates across all 87 species included in the analysis. The confidence intervals of the geometric mean were identified via bootstrapping (see methods below for further detail).

Table 1 The annual frequency of occurrence estimate across all species (Index) is shown alongside the 95% confidence intervals

Year	Index	2.5% CI	97.5% CI
1970	100.00	100.00	100.00
1971	99.78	98.39	101.40
1972	99.57	96.99	102.59
1973	99.72	95.82	104.31
1974	99.86	94.65	106.08
1975	100.01	93.49	107.85
1976	100.16	92.34	109.69
1977	100.30	91.22	111.55
1978	100.45	90.09	113.54
1979	100.60	88.94	115.52
1980	100.75	87.85	117.51
1981	100.89	86.73	119.56
1982	100.80	85.57	120.73
1983	100.48	84.42	121.27
1984	100.16	83.34	122.18
1985	99.84	82.21	122.70
1986	99.53	81.07	123.47
1987	99.21	79.97	124.24
1988	98.90	78.87	125.17
1989	98.58	77.75	126.02
1990	98.27	76.66	126.79
1991	97.95	75.61	127.88
1992	97.64	74.55	128.76
1993	97.33	73.52	129.66
1994	97.02	72.49	130.58
1995	96.61	71.46	131.32
1996	96.07	70.37	131.71
1997	95.58	69.38	132.14
1998	95.24	68.57	132.89
1999	94.90	67.72	133.71
2000	94.59	66.89	134.33
2001	94.42	66.30	135.04
2002	94.25	65.66	135.79
2003	94.08	65.13	136.47
2004	93.90	64.49	137.49
2005	93.73	63.78	138.23
2006	93.56	63.19	139.39

2007	93.39	62.64	140.35
2008	93.21	62.04	141.45
2009	93.04	61.40	142.30
2010	92.87	60.80	143.20
2011	92.71	60.27	144.13

Methodology:
The priority invertebrate species indicator was produced by following the methodology of the *C4b: Status of priority species – frequency of occurrence – insects* section within the UK biodiversity indicators 2014 report (http://jncc.defra.gov.uk/page-4229).

Biological records were extracted at the 1 km grid square scale from data held within the Biological Records Centre, the Bee, Wasps and Ants (BWARS) recording database and the records database of the British Dragonfly Society. Only data between 1970 and 2011 were included in the analysis; time lags in data collation prevented the inclusion of more recent records. Such biological records tend to contain many forms of sampling bias (for example between-year variation in recorder effort), making it hard to detect genuine signals of change. To account for this, we utilised the "well-sampled sites" mixed effects model approach of Roy *et al*. 2012 (see GMEP year 2 report). The annual index for each species was based on the fitted annual occupancy estimates from each species-specific models. Each species' time-series was expressed as the proportion of the first year which was set to 100. The overall annual indicator was then estimated as the geometric mean of the annual index values across all species. Confidence intervals were calculated via bootstrapping (n = 10,000). For each iteration, a random sample of species were selected with replication and the geometric mean recalculated.

Long-term trends in section 42 butterfly species

Target: *Biodiversity*

Question type: *Long term trends*

Question: *What are the long-term trends in section 42 butterfly species abundance across Wales?*

Background to question:

Section 42 of the Natural Environment & Rural Communities Act 2006 lists 189 invertebrate species of principal importance for conservation of biological diversity in Wales. Fifteen are butterflies. Evidence to date has shown that the combined effects of land-use change and climate have been responsible for changes in population size and range of many species. Those characteristic of less productive semi-natural habitats have fared the worst while rare species are additionally vulnerable because of their small and dispersed populations. Groups of Glastir measures are targeted at particular habitats and species, including three section 42 butterflies. By implementing habitat restoration and appropriate grazing and cutting regimes, these measures should favour butterfly larval foodplants and appropriate vegetation structure. The impact of these measures on butterfly abundance is best assessed against the backdrop of past and current trends in numbers. Here, long-term trend results are presented for section 42 butterflies in Wales based on UK Butterfly Monitoring Scheme (UKBMS) recording, as a context for interpreting further changes that may be attributed to Glastir.

Evidence:

Six of the 15 section 42 butterfly species had enough Welsh records to calculate changes in population indices. Trends over 38 years (1976-2013) and the past 10 years are consistent with the total abundance indices for Habitat Specialists (see BD009.2). Over the longer period most species declined showing more stability in the past 10 years. The last two columns show counts in the GMEP squares in 2013 and 2014 combined. The three species targeted by specific bundles of interventions in Glastir are highlighted in red and were rare or unrecorded in the Gmep transect surveys in 2013 and 2014.

Data:

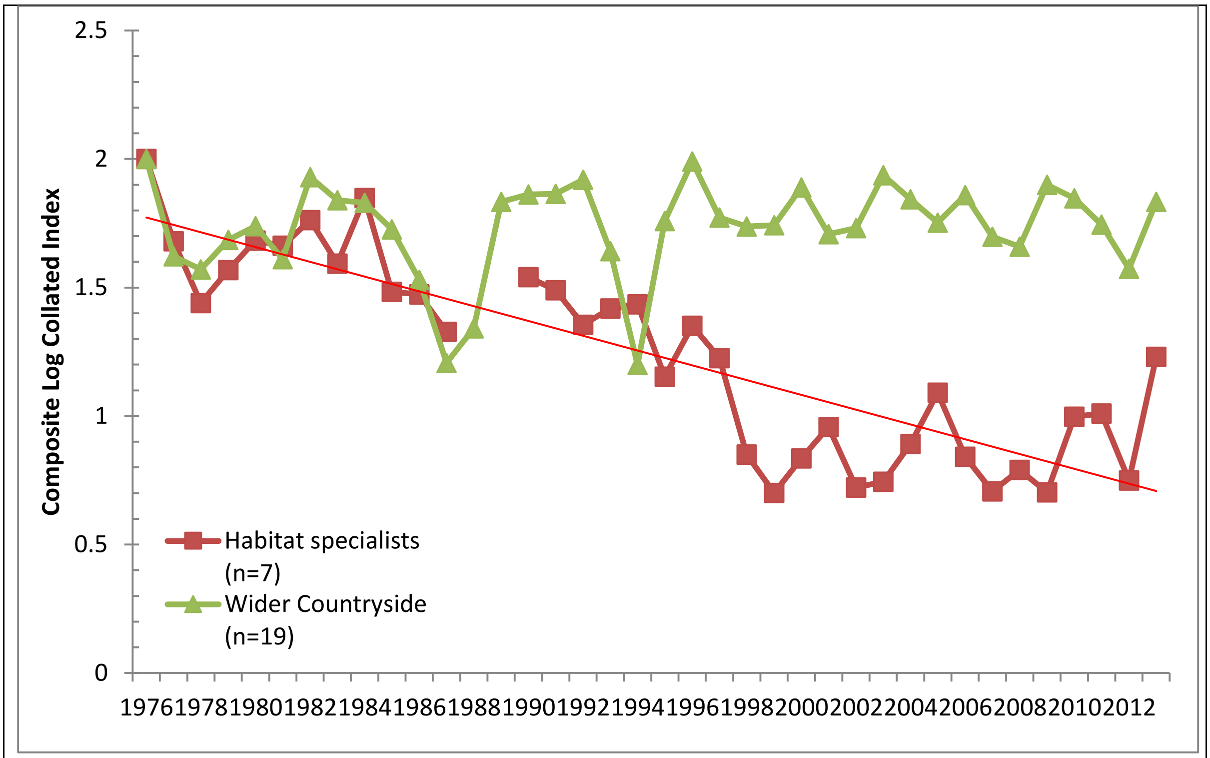
SPECIES	No. years used in trend	No. sites 2013	% change in index 2012-2013	Series trend (38-yrs)	10-yr trend	No. GMEP sites 2013-14	% GMEP sites 2013-14
Dingy Skipper	N/A	5	N/A	N/A	N/A	0	0
Grizzled Skipper	N/A	0	N/A	N/A	N/A	0	0
Wood White	N/A	0	N/A	N/A	N/A	0	0
Brown Hairstreak	N/A	1	N/A	N/A	N/A	1	1
White-letter Hairstreak	N/A	2	N/A	N/A	N/A	2	1
Small Blue	N/A	2	N/A	N/A	N/A	0	0
Silver-studded Blue	N/A	1	N/A	N/A	N/A	0	0
White Admiral	N/A	0	N/A	N/A	N/A	0	0
Small Pearl-bordered Fritillary	15	7	-9	-24	89	6	4
Pearl-bordered Fritillary	16	12	74	171*	72	0	0
High Brown Fritillary	10	9	990	-8	-33	1	1
Marsh Fritillary	21	20	272	-79**	-44	0	0
Wall Brown	38	36	476	-38	39	24	16

Grayling	32	7	447	-84***	257*	3	2
Large Heath	N/A	0	N/A	N/A	N/A	2	1

Methodology:
Data are based on occupancy of Welsh UKBMS 1km squares. Because the species are rare, records are limited in number and so trends in the data, particularly those ranging back to 1976, should be interpreted with caution. Counts of presence in GMEP 1km squares were derived from pollinator surveys (see Pollinator survey results portal pages for further details).

Long-term trends in butterflies

Target: *Biodiversity*
Question type: *Long term national trends*
Question: *What are the long-term trends in butterfly abundance across Wales?*
Background to question: Butterfly numbers have declined at least since the 1970's as a result of habitat loss through land converted to agriculture and subsequent intensification. Because insect populations fluctuate annually in response to weather, parasitism, predation and other factors, it is essential to determine patterns over long-time series to see how populations are changing when these other effects are accounted for. Butterflies are important for a number of reasons; they are pollinators, prey for many other taxa, particularly birds, and are of cultural significance having a positive effect on people's well being. Whilst other invertebrate groups are also important for these and other ecosystem services we often lack sufficient data to determine patterns in abundance, whereas for butterflies we have a comprehensive dataset going back to 1976. In addition, analyses to date have revealed that other taxa are showing similar patterns across the UK, and butterflies have been shown not only to be good indicators of the general health of the countryside, but also good indicators of how other taxonomic groups are responding.
Evidence: UK Butterfly Monitoring Scheme (UKBMS) data is shown for Wales going back to 1976 (Fig 1). Butterfly species abundance in 324 1km squares has been collated and trend lines are shown for two groups: Wider Countryside species include generalists such as Meadow Brown (*Maniola jurtina*), Large White (*Pieris brassicae*) and Peacock (*Aglais io*), whose larvae feed on forbs and grasses abundant in productive farmland. These species are therefore able to survive better in the modern countryside and show a stable pattern with fluctuations reflecting the influence of the weather on population size. Habitat specialist species such as Pearl-bordered (*Boloria euphrosyne*) , High Brown (*Argynnis adippe*) Fritillaries, and the Grayling (*Hipparchia semele*) show greater restriction to less productive semi-natural habitats such as heathland and fen. The index for these species shows a rapid and highly significant decline in Wales since 1976, and appearing to stabilise at a lower abundance after 1998. Figure 1: Long term trends in butterfly abundance in Wales.



	No. species	Series trend (%)	Series trend description	10-yr trend (%)	10-yr trend description
All species	*26*	*-3*	*Stable*	*-7*	*Stable*
Wider Countrsyide species	*19*	*25*	*Stable*	*-16*	*Stable*
Habitat specialists	*7*	*-91****	*Rapid decline*	*38*	*Stable*

Methodology:
The UKBMS is a volunteer-based scheme that has been running since 1976 with well over 3,000 sites to date. Data on the population status of butterflies is derived from a national-scale programme of site-based monitoring and sampling in randomly selected 1km squares (Wider Countryside Butterfly Survey – WCBS). The majority of sites are monitored by butterfly transects involving weekly counts along fixed routes throughout the season. Counts are converted to a site index that accounts for both the size of the colony and the time in the season when the count was made. The WCBS was established in 2009 to improve data on national population status of butterflies across the countryside as a whole. For wider countryside species, data from the two main survey types are combined to create national indices for these species, whilst for habitat specialists which are more reliant on reduced effort monitoring, only BMS data is used. General Additive Models are used to calculate site-level indices for each recorded species. Following this a log-linear model is used to calculate a national collated index for each species. These indices are combined to calculate composite indices for each butterfly group. See http://www.ukbms.org/ for further details.

Nectar plant abundance on arable land

Target: *Biodiversity*

Question type: *Long term trends*

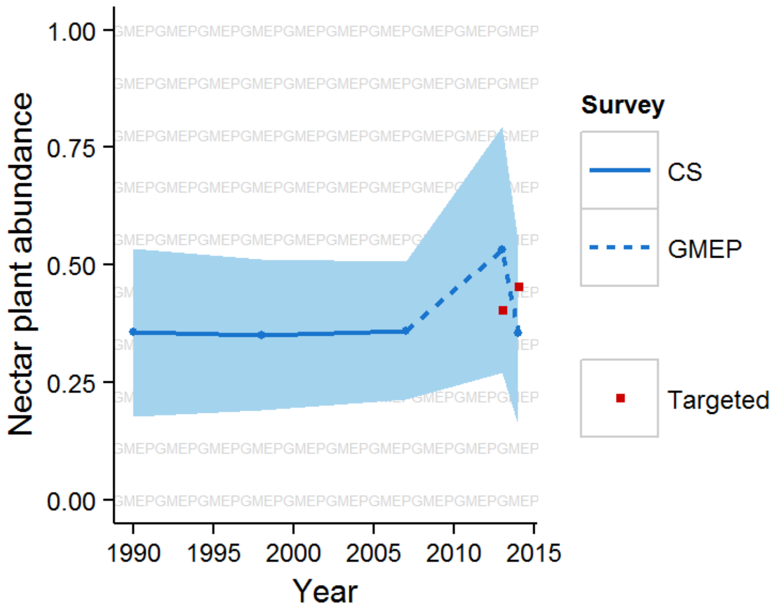
Question: Are nectar plants declining in Welsh arable land?

Background to question:
Pollinating invertebrates and their wild nectar plants have been declining across NW Europe since the 1950s. In many places this has led to a pollinator deficit reducing potential supply of the ecosystem service of crop pollination and reducing the biodiversity of nectar plants and their pollinating insects. Over time GMEP surveys can be used to quantify jointly recorded changes in abundance of preferred nectar plants and pollinating insects and estimate how they are impacted by Glastir. To interpret these future patterns it is essential to understand what has happened in the past. To do this GMEP survey data can be linked up with longer term records from Countryside Survey. Three examples are presented that quantify changes in the abundance of the most common nectar-providing plants since 1990. Some habitats are more important than others in supporting these plant species. Here we focus on data from the Arable & Horticultural Broad Habitat. This habitat is however, less extensive in Wales than other parts of the UK hence sample sizes were small (11 area and 20 linear plots in 2013; 19 and 26 respectively in 2014).

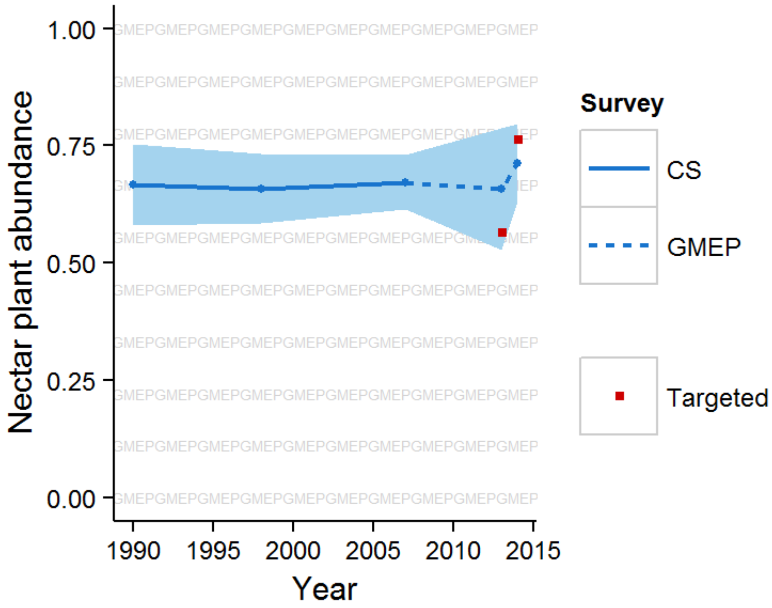
Evidence:
There were no significant differences in abundance of important nectar plants between any pair of years. Mean nectar plant abundance was roughly 30% higher in linear plots than in plots sampling the interior of arable fields (Fig 1a,b).

Figure 1: Mean cover-weighted abundance of nectar plants in a) plots that randomly sample areas of arable land, b) plots from linear features associated with arable land.

a)



b)



Data:
CSV supplied.

Methodology:
GMEP survey datasets:
Plots that randomly sampled areas of habitat or linear features associated with the arable land (field boundaries, adjacent watercourses and hedgerows) were selected from Countryside Survey and GMEP where every plot was linked to a mapped area of Arable & Horticultural Broad Habitat. Because of sample size differences and reflecting the unique importance of linear features, particularly adjacent to arable fields, area and linear plots were analysed separately.

Indicators:
The indicator was calculated by first ranking the preferred foodplants listed in Dyer, R et al (2014). *The Identification of Preferential Foodplants for Pollinator Species of Concern in the UK. Report to Natural England*. The attribute used to rank each species was the total number of observed pollinator-plant interactions. The highest ranking species were Bramble (*Rubus fruticosus* agg.), Ragwort (*Senecio jacobaea*) and Hogweed (*Heracleum sphondylium*). Rank importance of each species was scaled to between 0 (least important) and 1 (most important). The mean rank of the species in each GMEP plot was then derived and the importance of the species additionally weighted by its observed cover so that high ranking plants with greater cover result in values of the indicator closer to 1.

Nectar plant abundance in Neutral Grassland

Target: *Biodiversity*

Question type: *Long term trends*

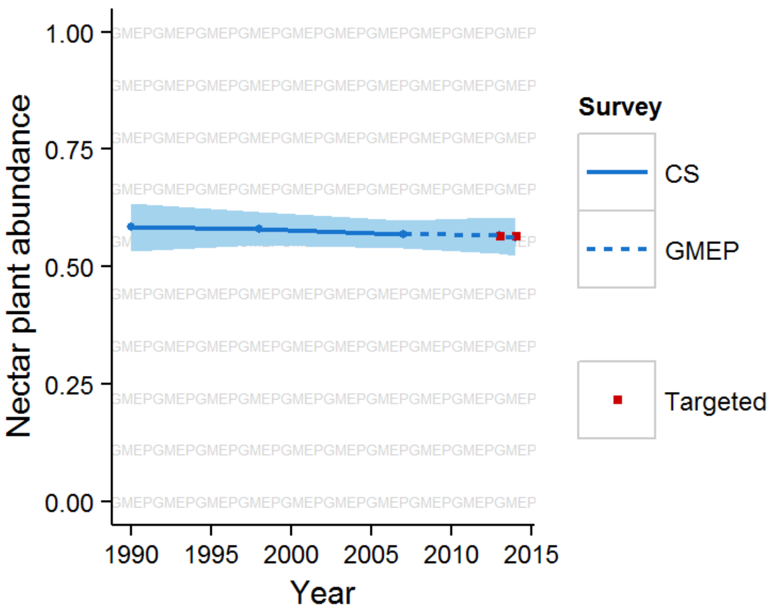
Question: Are nectar plants declining in Welsh Neutral Grassland?

Background to question:
Pollinating invertebrates and their wild nectar plants have declined across NW Europe since about the 1950s. In many places this has led to a pollinator deficit reducing potential supply of the ecosystem service of crop pollination and reducing the biodiversity of nectar plants and their pollinating insects. Over time GMEP survey data can be used to quantify jointly recorded changes in abundance of preferred nectar plants and pollinating insects and estimate how they are impacted by Glastir. To interpret these future patterns it is essential to understand what has happened in the past. To do this GMEP surveys can be linked up with longer term records from Countryside Survey. Three examples are presented that quantify changes in the abundance of the most common nectar-providing plants since 1990. Some habitats are more important than others in supporting these plant species. Here, data is presented from the Neutral Grassland Broad Habitat.

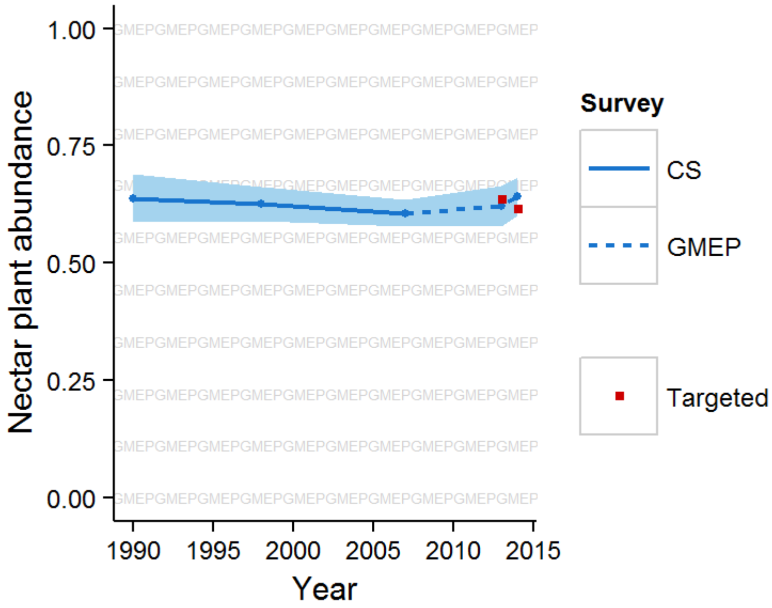
Evidence:
There were no significant differences in abundance of important nectar plants between any pair of years.

Figure 1: Mean cover-weighted abundance of nectar plants in a) plots that randomly sample areas of Neutral Grassland, b) plots from linear features associated with Neutral Grassland.

a)



b)



Data:

CSV supplied.

Methodology:

GMEP survey datasets:

Plots that randomly sampled areas of habitat or linear features associated with Neutral Grassland (field boundaries, adjacent watercourses and hedgerows) were selected from Countryside Survey and GMEP where every plot was linked to a mapped area of Neutral Grassland. Because of sample size differences and reflecting the unique importance of linear features, area and linear plots were analysed separately.

Indicators:

The indicator was calculated by first ranking the preferred foodplants listed in Dyer, R et al (2014). *The Identification of Preferential Foodplants for Pollinator Species of Concern in the UK. Report to Natural England*. The attribute used to rank each species was the total number of observed pollinator-plant interactions. The highest ranking species were Bramble (*Rubus fruticosus* agg.), Ragwort (*Senecio jacobaea*) and Hogweed (*Heracleum sphondylium*). Rank importance of each species was scaled to between 0 (least important) and 1 (most important). The mean rank of the species in each GMEP plot was then derived and the importance of the species additionally weighted by its observed cover so that high ranking plants with greater cover result in values of the indicator closer to 1.

Nectar plant abundance in Broadleaved woodland

Target: *Biodiversity*

Question type: *Long term trends*

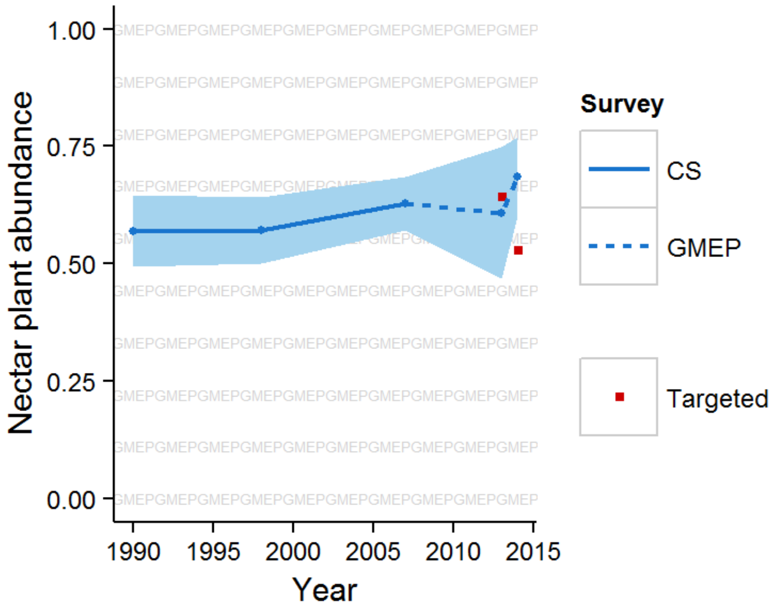
Question: Are nectar plants declining in Welsh broadleaved woodland?

Background to question:
Pollinating invertebrates and their wild nectar plants have declined across NW Europe since about the 1950s. In many places this has led to a pollinator deficit reducing potential supply of the ecosystem service of crop pollination and reducing the biodiversity of nectar plants and their pollinating insects. Over time GMEP survey data can be used to quantify jointly recorded changes in abundance of preferred nectar plants and pollinating insects and estimate how they are impacted by Glastir. To interpret these future patterns it is essential to understand what has happened in the past. To do this GMEP field survey data can be linked up with longer term records from Countryside Survey. Three examples are presented that quantify changes in the abundance of the most common nectar-providing plants since 1990. Some habitats are more important than others in supporting these plant species. Here we focus on data from the Broadleaved, Mixed & Yew woodland Broad Habitat. The other indicators present data from the Neutral Grassland and Arable & Horticultural Broad Habitats.

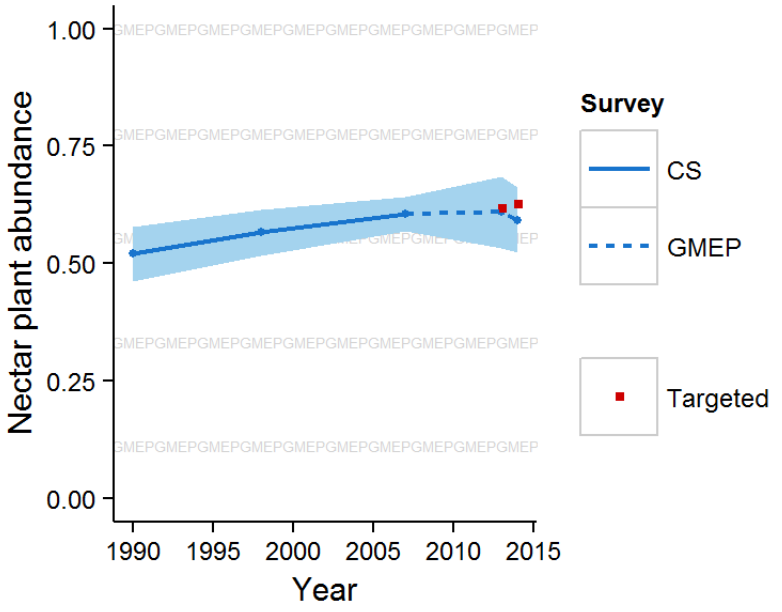
Evidence:
There were no significant differences in abundance of important nectar plants between any pair of years.

Figure 1: Mean cover-weighted abundance of nectar plants in a) plots that randomly sample areas of woodland, b) plots from linear features inside or on the edge of woodlands.

a)



b)



Data:
CSV supplied.

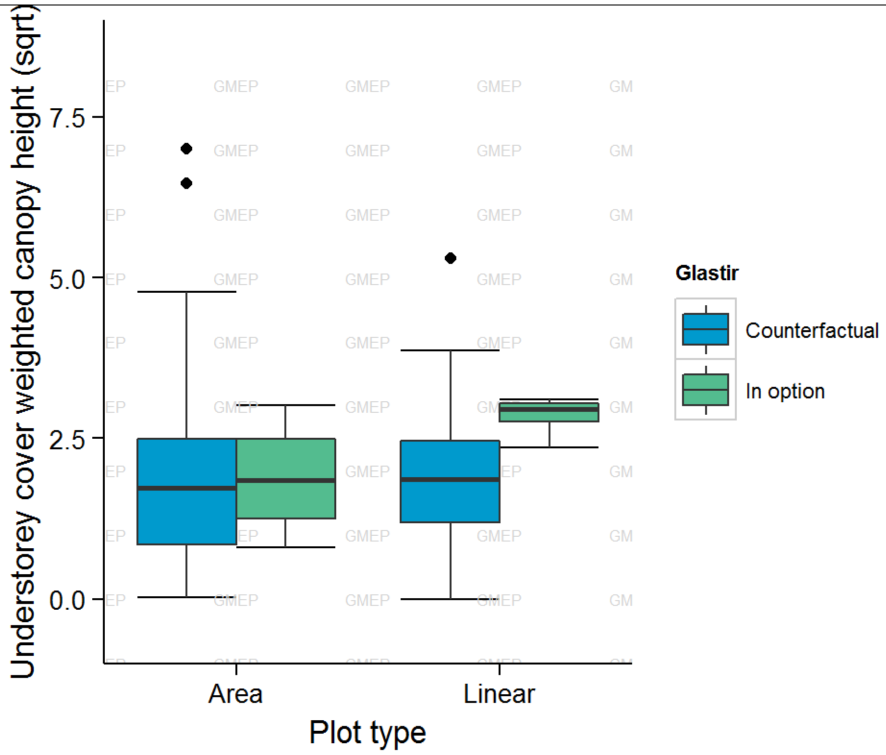
Methodology:
GMEP survey datasets:
Plots that randomly sampled areas of woodland or linear features associated with woodland (woodland boundaries, adjacent watercourses and hedgerows) were selected from Countryside Survey and GMEP where every plot was linked to a mapped area of woodland. Because of sample size differences and reflecting the unique importance of linear features, area and linear plots were analysed separately.

Indicators:
The indicator was calculated by first ranking the preferred foodplants listed in Dyer, R et al (2014). *The Identification of Preferential Foodplants for Pollinator Species of Concern in the UK. Report to Natural England*. The attribute used to rank each species was the total number of observed pollinator-plant interactions. The highest ranking species were Bramble (*Rubus fruticosus* agg.), Ragwort (*Senecio jacobaea*) and Hogweed (*Heracleum sphondylium*). Rank importance of each species was scaled to between 0 (least important) and 1 (most important). The mean rank of the species in each GMEP plot was then derived and the importance of the species additionally weighted by its observed cover so that high ranking plants with greater cover result in values of the indicator closer to 1.

Headline question: What are the impacts of Glastir options on conditions associated with section 42 species?

Dormouse; habitat condition indicators

Target: *Biodiversity*
Question type: *Benefit of Glastir options*
Question: What is the impact of the Glastir options on ecological conditions associated with Dormouse?
Background to question: Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to encompass target species populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' performance but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with GMEP squares with relevant option uptake.
Evidence: Glastir uptake: Of 20 Dormouse options 9 have been taken up in at least one Gmep square. The most common options focus on hedgerow management (5, 6, 6b) and stock exclusion in woodlands (100). Example indicators were generated to measure changes in shrub species composition and the structure of the woodland understorey, as well as species richness of shrubs in trees in hedgerows. . Coincidence with target species: Available distribution data for Dormouse indicated no post-1970 records in any of the 27 Gmep squares containing Dormouse options. This is likely to be an underestimate since it was not possible to access a large proportion of known Dormouse records for Wales. Indicators: In woodlands, understorey canopy height did not differ significantly between in-option and out of scheme plots but Bramble cover was higher within in-option plots because of much higher values on linear features (Fig 1b). In hedgerows, in-option and out of scheme plots did not differ in total tree and shrub species richness (Fig 2). Figure 1: Plots in option 100 (woodland stock exclusion) compared to out of scheme plots in broadleaved woodland. Mean cover-weighted canopy height per plot a) where canopy height per species was classified as follows: *1.* foliage <100mm in height; *2.* 101-299mm; *3.* 300-599mm; *4.* 600-999mm; *5.* 1.0-3.0m; *6.* 3.1-6.0m; *7.* 6. 1-15.0m; *8.* >15m. Cover of Bramble b). a)



b)

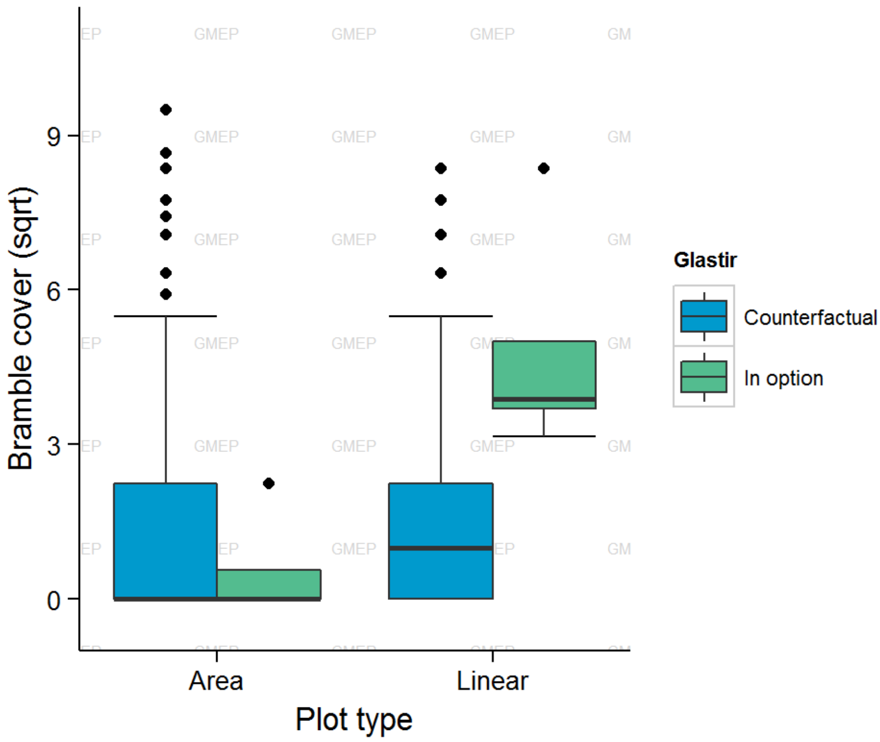
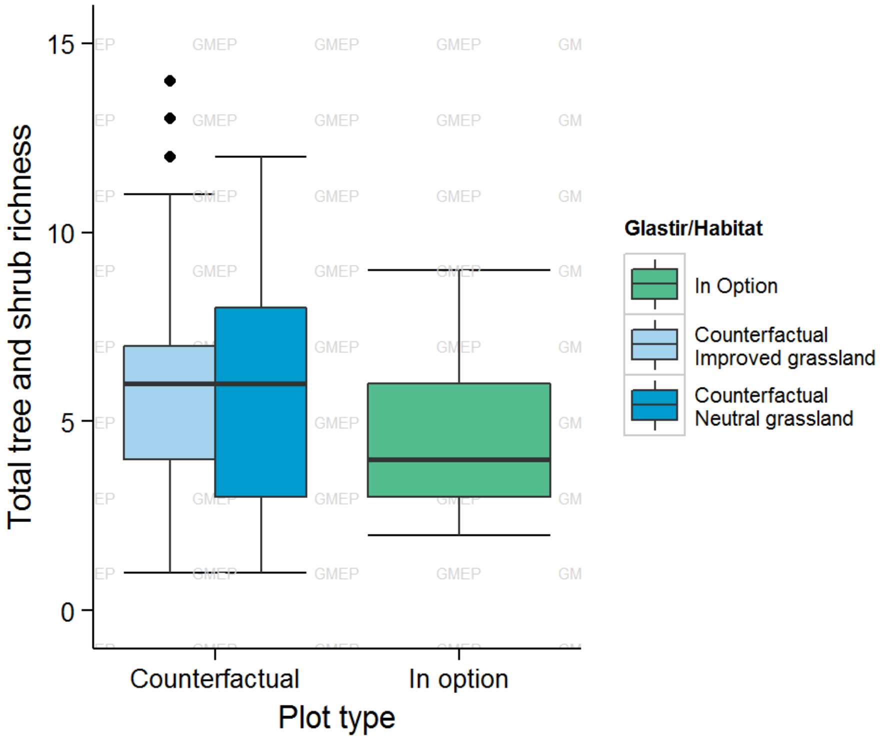


Figure 2: Total tree and shrub richness in 30m long hedgerow plots contrasting those in hedgerow management options with out of scheme hedgerows. Note that in-option plots were either adjacent to Improved (7 plots) or Neutral grassland (2 plots) but were too few in number to analyse by broad habitat. Hence counterfactual hedgerow plots next to either habitat type are shown separately for comparison.



Data:

CSV supplied.

Methodology:

Gmep field survey datasets:

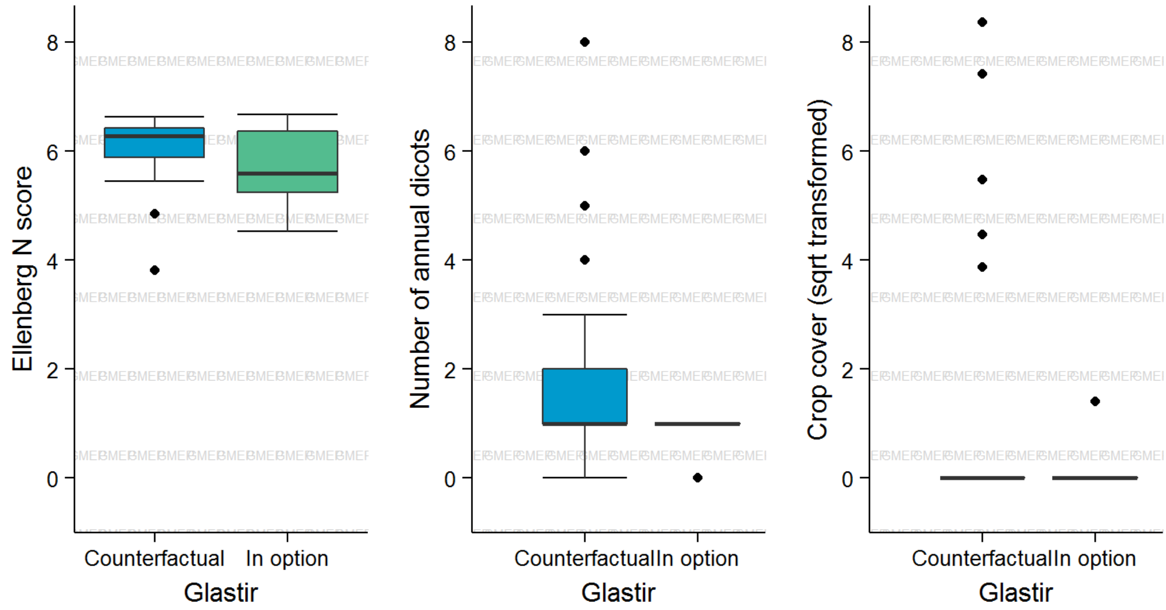
Uptake of Dormouse options was sufficient to support a comparison of plots in hedgerows and woodlands both in-option and out of scheme. Dataset size for hedgerows was very small. More coverage of options will be available following the year 3 and 4 surveys, which will also involve better targeting of options.

Indicators:

Indicator variables were selected as those best able to convey the impact of the options on ecological conditions important for the target species. Dormice benefit from a taller understorey that should develop and persist following exclusion of stock. Hence, cover-weighted canopy height was calculated based on the known average foliage heights of the species recorded. Cover of major foodplants – Bramble and Honeysuckle - were also extracted. Honeysuckle was too rare to analyse. As Gmep encounters increasing levels of uptake, analysis of more indicator variables will be possible, for example data relating to hedgerow structure, dimensions and condition.

Rare arable plants; habitat condition indicators

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: *What is the impact of the Glastir options on ecological conditions associated with Rare Arable Plants (RAP)?*
Background to question: Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to encompass target species populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' performance but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with Gmep squares with relevant option uptake.
Evidence: Glastir uptake: Of 9 RAP options, 5 occur in Gmep squares but only 3 (30,33 and 32b) had enough plot data (n=5) to evaluate ecological differences between in-option and out of scheme land. This is a very small sample size. The number should increase with the addition of yr 3 and 4 squares and a shift to better targeting of option land. Coincidence with target species: Of 16 Gmep 2013/'14 squares where RAP options were present, none had recent recorded occurrences of rare Arable Plants (Plantlife data) and none were recorded in any of the squares during the 2013 and '14 Gmep field surveys. Indicators: Annual dicot richness was significantly higher in the counterfactual plots. This is certainly because the small number of plots in RAP options were still improved grassland at the time of survey. As the ground experiences low intensity cultivation associated with the requirements of the options, then all three indicators should change. In comparison with cultivated cropland out of scheme the expectation would be for a reduction in fertility score over time, an increase in crop cover and an increase in annual dicot richness in response to the three options but note that fertilisers are allowed under options 30 and 32b. Figure 1: Comparison of plots in RAP options in Gmep squares (2013/'14) with out of scheme arable plots. Three variables are shown indicating fertility levels, richness of non-crop forbs and cover of crop.



Data:
CSV supplied.

Methodology:
Gmep field survey datasets:
Low uptake of RAP options in Gmep squares reflected low uptake in Wales as a whole. This resulted in only 5 vegetation plots being in-option in the Gmep field surveys of 2013/'14. These plots were contrasted with the same types of plots selected on out of scheme arable land as the counterfactual.

Caveats:
While Gmep field survey explicitly targets the interior and edges of arable fields, rare arable plants have a localised distribution in Wales and are rare and ephemeral in occurrence where they do occur. Hence it is unlikely that Gmep field survey will ever accumulate enough records of these species to be able to directly evaluate their abundance in terms of the effects of Glatrir options.

Curlew; habitat condition indicators

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: What is the impact of the Glastir options on ecological conditions associated with Curlew?
Background to question: Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to support target species' populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future, it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' performance but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with Gmep squares with relevant option uptake.
Evidence: <u>Glastir uptake:</u> Of 17 Curlew options 5 have been taken up in at least one Gmep square. The most common options focused on grazing of open country (41a,b) and upland grassland (18) . Enough plots coincided with these options to allow assembly of in-option and out of scheme data. Of the 17 Curlew options all but one were taken up somewhere in Wales up to the end of 2014. <u>Coincidence with target species:</u> Curlew were recorded in 2 of the 29 Gmep 2013 and '14 squares with sufficient option area to be analysed. Overall, Curlew were recorded in 22 of the 150 Gmep squares. <u>Indicators:</u> In both Bog and Acid grassland, vegetation was most often between 15 and 40cm in height (Fig 1). None of the indicators differed significantly between in-option and out of scheme land (Fig 2). Figure 1: Measured vegetation heights in Gmep area plots in option (41a,b,18) or out of scheme in 2013/14 field survey. 1; None, 2; 0-7cm, 3; 7-15cm, 4; 15-40cm, 5; 40cm-1m, 6; >1m.

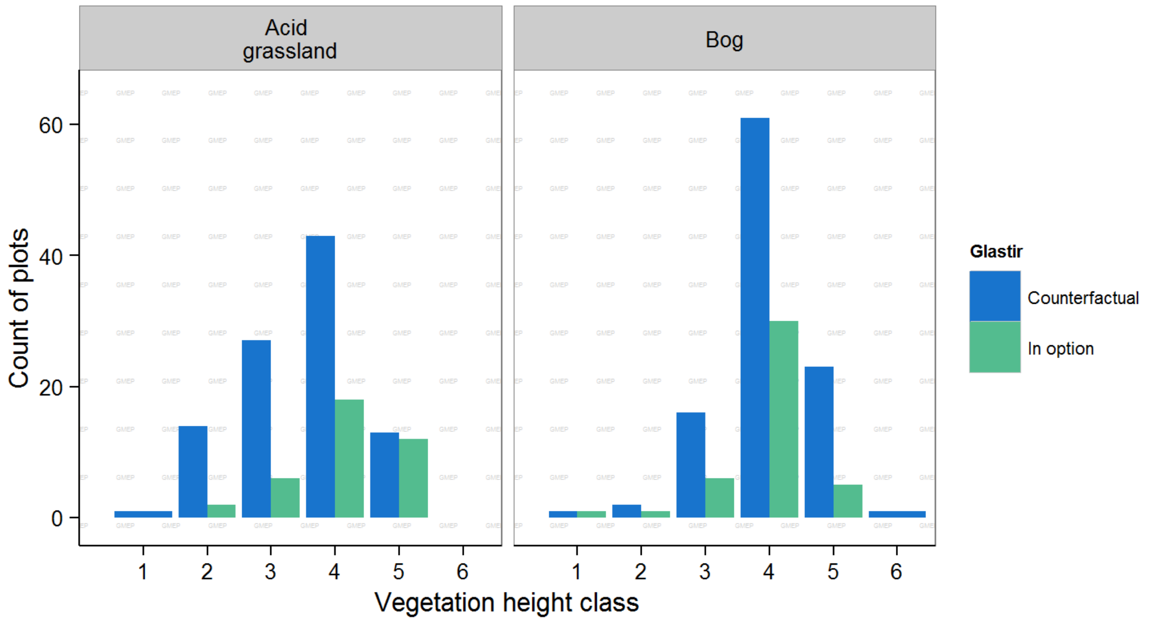
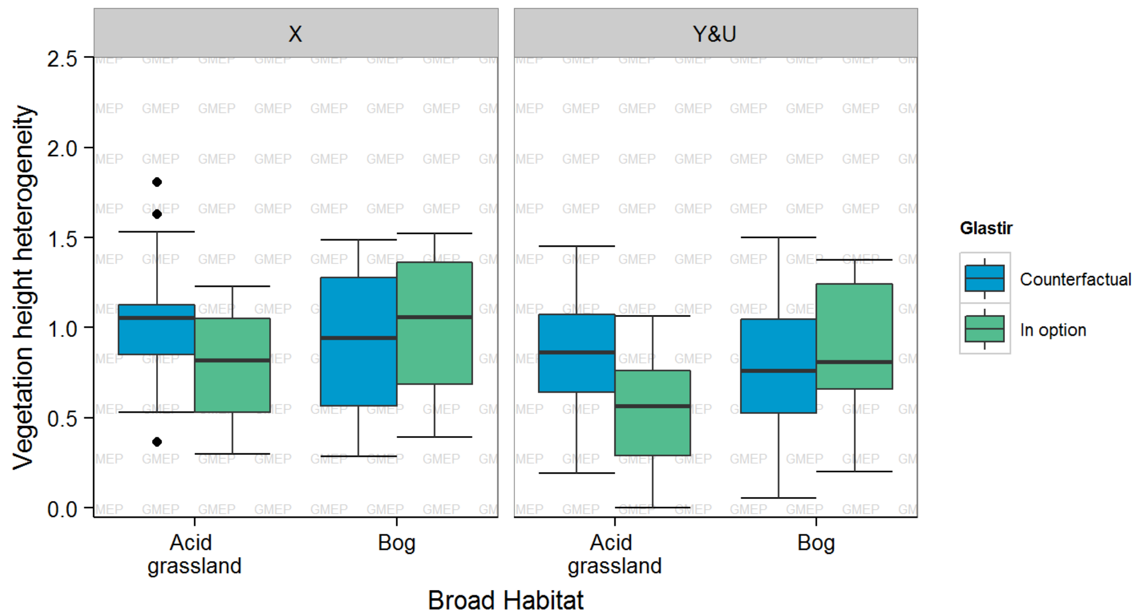
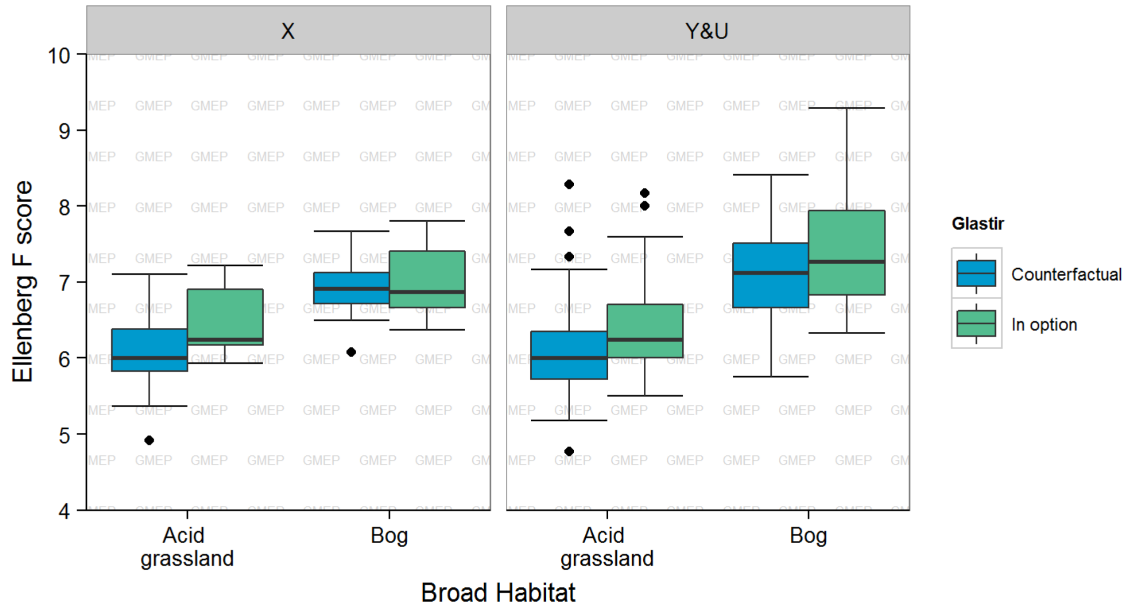


Figure 2: Indicators derived from the plant species composition of random X plots versus plots targeted on priority habitats (Y) or 'open country' broad habitats (U). Vegetation heterogeneity a), wetness index b) and rush cover c).

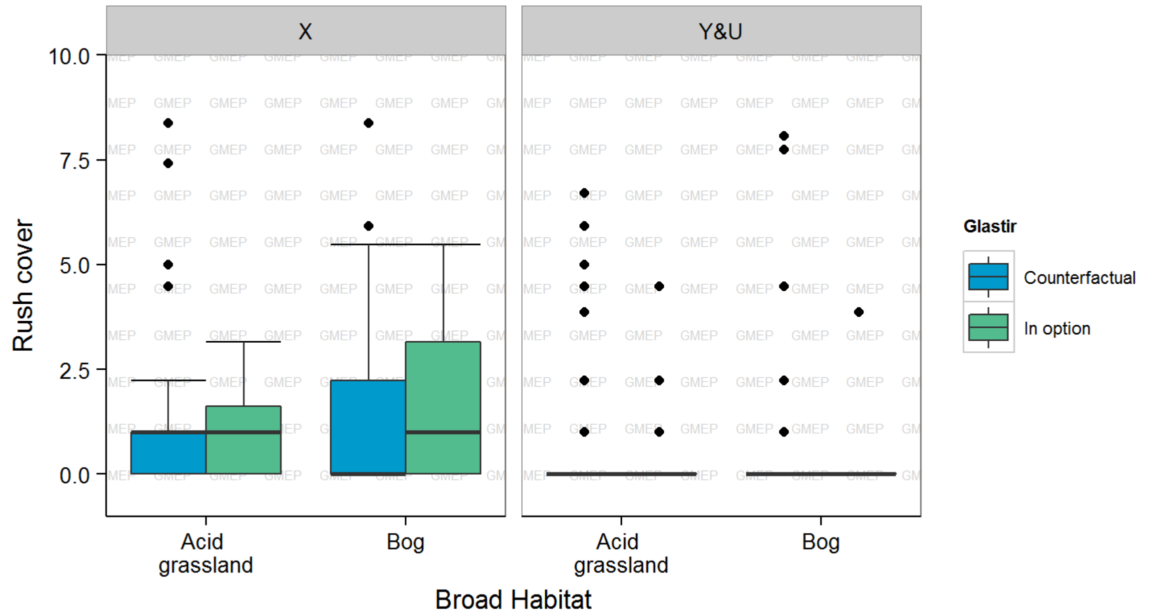
a)



c)



b)



Data:
CSV supplied.

Methodology:
Gmep field survey datasets:
Since Curlew nest in open land away from field boundaries, area plots only were selected for analysis. Enough data were available for comparison of in-option versus out of scheme plots in Acid grassland and Bog broad habitats. The dataset was split into two groups; 200m^2 X plots that randomly sample all land, and 4m^2 plots targeted onto priority habitats (Y) or 'open country' habitats.

Indicators:
Indicators measured changes in rush cover (*Juncus* spp.), observed vegetation height and presence of moisture-loving plants; the higher the wetness index the greater the cover of plants

indicating wet conditions. Since Curlews tend to select breeding habitat where vegetation varies in height forming a mosaic structure, a measure of vegetation heterogeneity was also calculated. Plant species with the same average foliage height class were grouped and their total cover summed. A diversity index was then calculated on the variation in cover-weighted height classes in each plot. Higher values indicate cover of a wider range of plant heights. The distributions of vegetation heights recorded in plots during the field survey were also extracted. Over time the expectation would be for appropriate grazing under Curlew options to maintain or reduce vegetation height, maintain or create vegetation mosaic structure, maintain or reduce rush cover where dominant and maintain or increase vegetation wetness relative to out of scheme land.

Lapwing; habitat condition indicators

Target: *Biodiversity*

Question type: *Benefit of Glastir measures*

Question: *What is the impact of the Glastir options on ecological conditions associated with Lapwing?*

Background to question:
Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to support target species' populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' presence but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with Gmep squares with relevant option uptake.

Evidence:
Glastir uptake: Of 14 Lapwing options 4 have been taken up in at least one Gmep square. The most common options focused on grazing of open country (41a,b). Enough plots coincided with these options to allow assembly of in-option and out of scheme data.

Coincidence with target species:
Lapwing were recorded in 2 of the 27 Gmep 2013 and '14 squares with enough option land for analysis.

Indicators:
In both Bog and Acid grassland, vegetation was most often between 15 and 40cm in height based on measurements in 200m^2 plots (Fig 1). None of the indicators differed significantly between in-option and out of scheme land (Fig 2).

Figure 1: Measured vegetation heights in Gmep 200m^2 plots in option (41a,b) or out of scheme in 2013/14 field survey. 1; None, 2; 0-7cm, 3; 7-15cm, 4; 15-40cm, 5; 40cm-1m, 6; >1m.

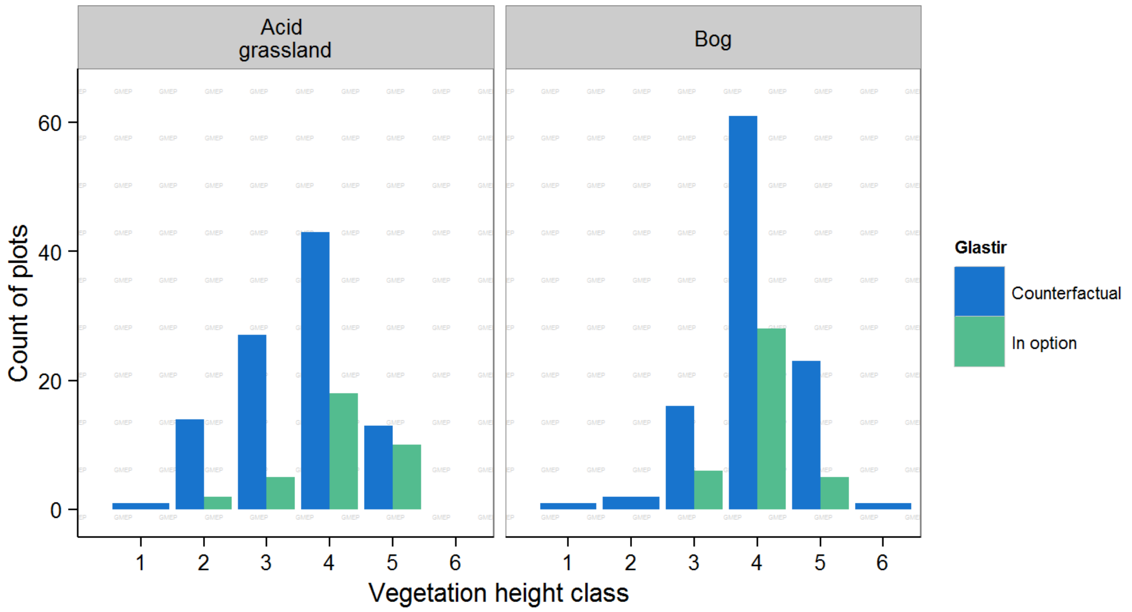
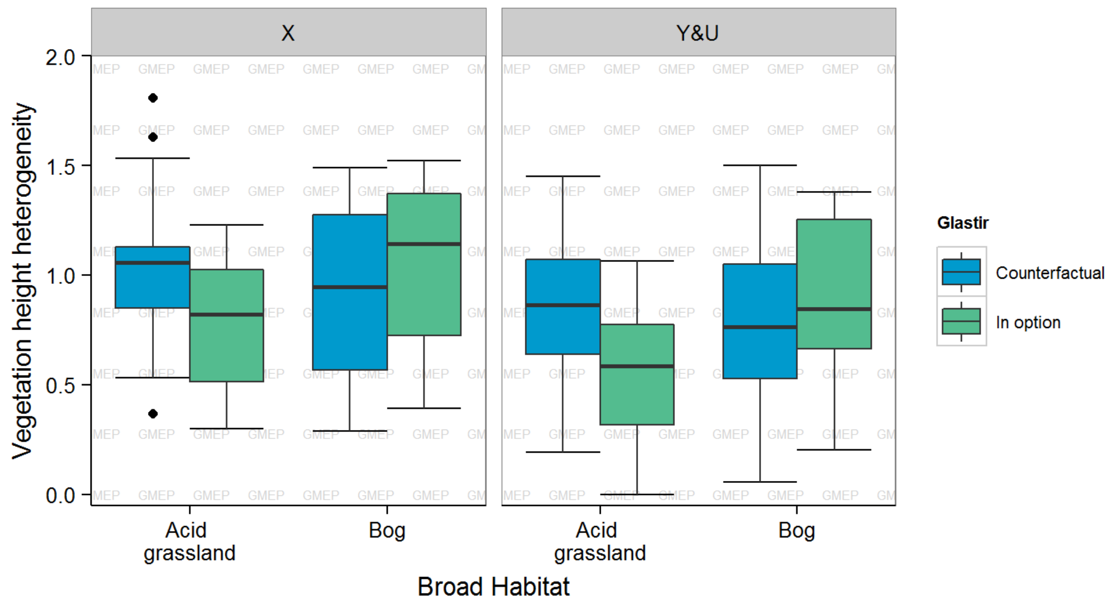
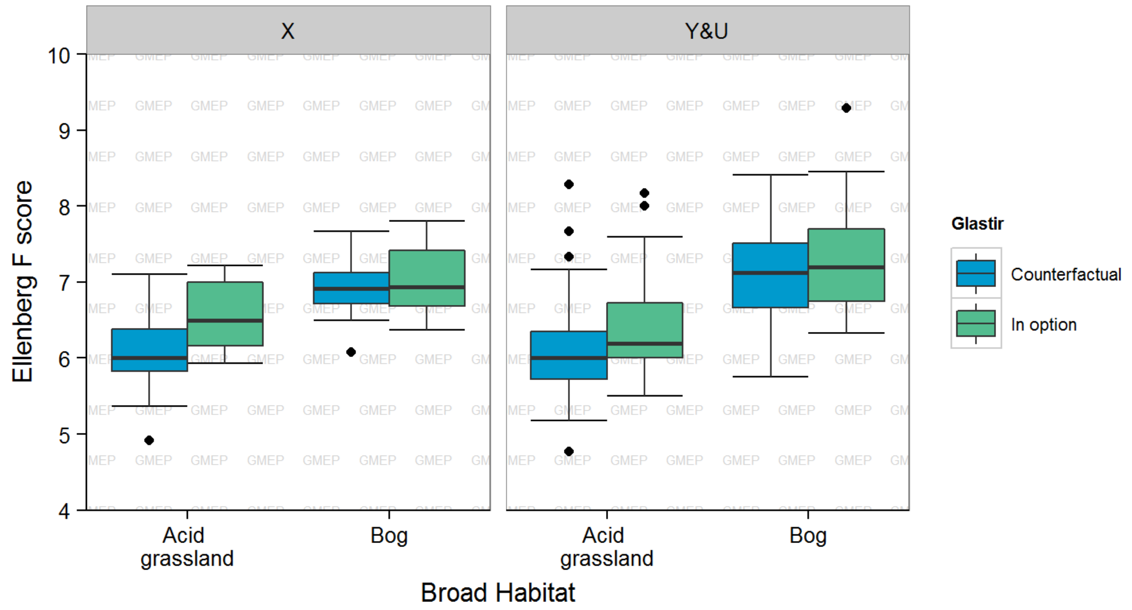


Figure 2: Indicators derived from the plant species composition of random X plots versus plots targeted on priority habitats (Y) or 'open country' broad habitats (U). Vegetation heterogeneity a), wetness index b) and rush cover c).

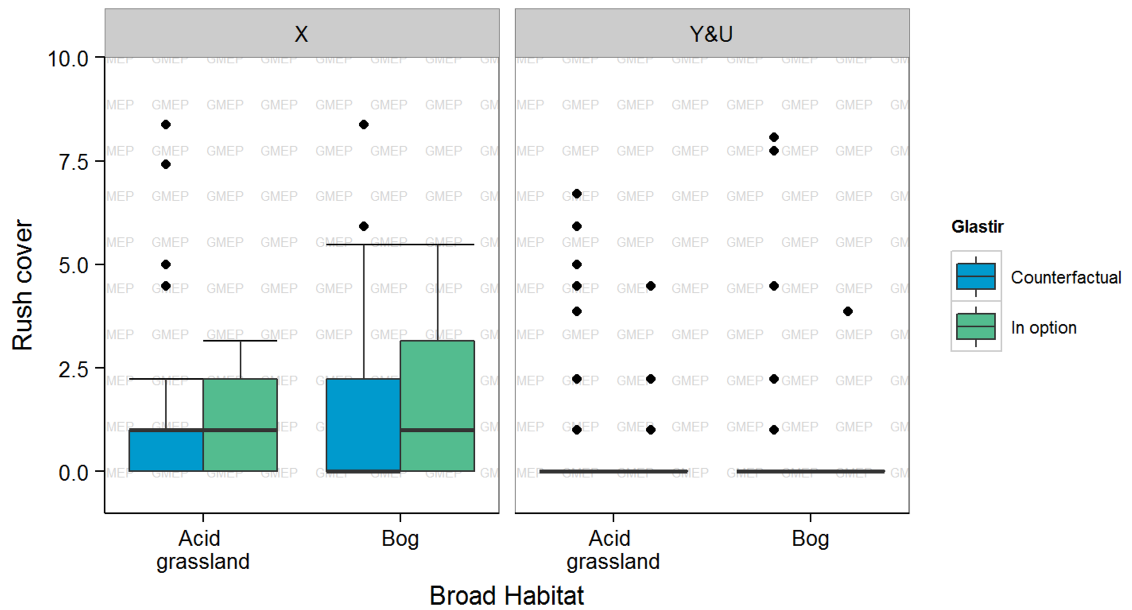
a)



b)



c)



Data:
CSV supplied.

Methodology:
Gmep field survey datasets:
Since Lapwing nest in open land away from field boundaries, area plots only were selected for analysis. Enough data was available for comparison of in-option versus out of scheme plots in Acid grassland and Bog broad habitats so as to achieve like with like comparison. The dataset was split into two groups, 200m^2 X plots that randomly sample all land, and 4m^2 plots targeted onto priority habitats (Y) or 'open country' habitats (U).

Indicators:
Indicators measured changes in rush cover (*Juncus* spp.), observed vegetation height and presence of moisture-loving plants; the higher the wetness index the greater the cover of plants

indicating wet conditions. Since Lapwing select nesting habitat where vegetation varies in height forming a mosaic structure, a measure of vegetation heterogeneity was also calculated. Plant species with the same average foliage height class were grouped and their total cover summed. A diversity index was then calculated on the variation in cover-weighted height classes in each plot. Higher values indicate cover from a wider range of plant heights. The distributions of vegetation heights recorded in plots during the field survey were also extracted. Over time the expectation would be for appropriate grazing under Lapwing options to maintain or reduce vegetation height, maintain or create vegetation mosaic structure, maintain or reduce rush cover where dominant and maintain or increase vegetation wetness relative to out of scheme land.

Lesser Horsehoe Bat; habitat condition indicators

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: *What is the impact of the Glastir options on ecological conditions associated with Lesser Horseshoe Bat (LHB)?*
Background to question: Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to encompass target species populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' performance but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with Gmep squares with relevant option uptake.
Evidence: <u>Glastir uptake:</u> Of 91 LHB Glastir options, 32 occur in Gmep squares but only 10 (133, 134, 15c, 19, 19b, 22, 15b, 15, 15d, 41a) had enough plot data (n=157) to evaluate ecological differences between in-option and out of scheme land. This number will increase with the addition of yr 3 and 4 squares and a shift to better targeting of option land. <u>Coincidence with target species:</u> Of 81 Gmep 2013/'14 squares where LHB options are present, 5 have post-2000 recorded occurrences of LHB (Bat Conservation Trust data). <u>Indicators:</u> Out of scheme land was broadly similar to in-option land across the four broad habitats. Ellenberg fertility score was significantly higher in the out of scheme counterfactual plots in Fen, marsh & swamp and Acid grassland. Since all options stipulate appropriate grazing and low or zero fertiliser inputs we would expect indicator values to be maintained relative to out of scheme land or to change consistent with reduced fertility, more wetland species and higher plant species richness. Figure 1: Plots in Acid grassland in option versus out of scheme.

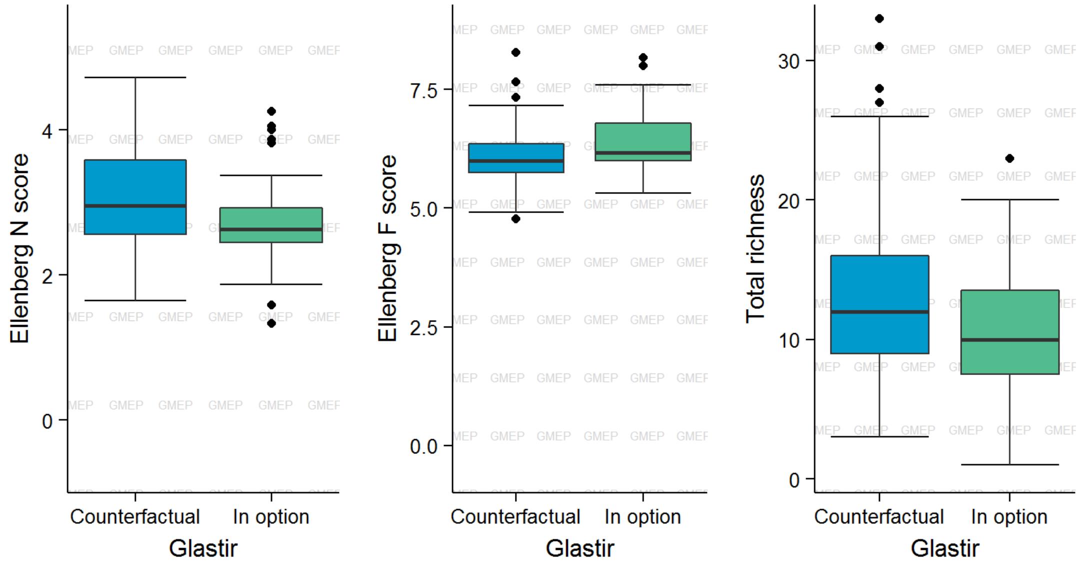


Figure 2: Bog in option versus out of scheme.

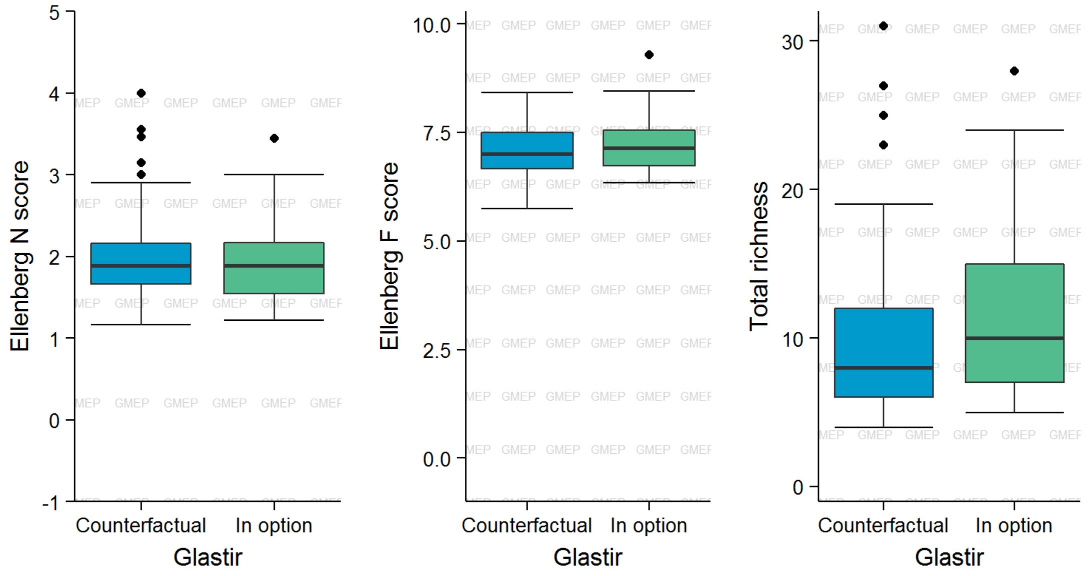


Figure 3: Bracken in option versus out of scheme.

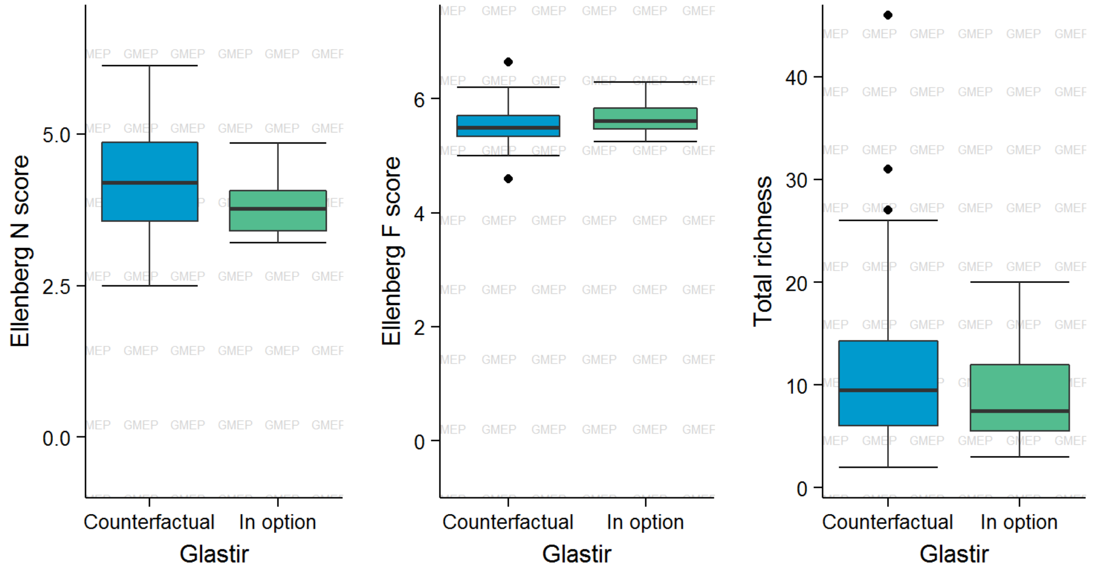


Figure 4: Fen, Marsh & Swamp in option versus out of scheme.

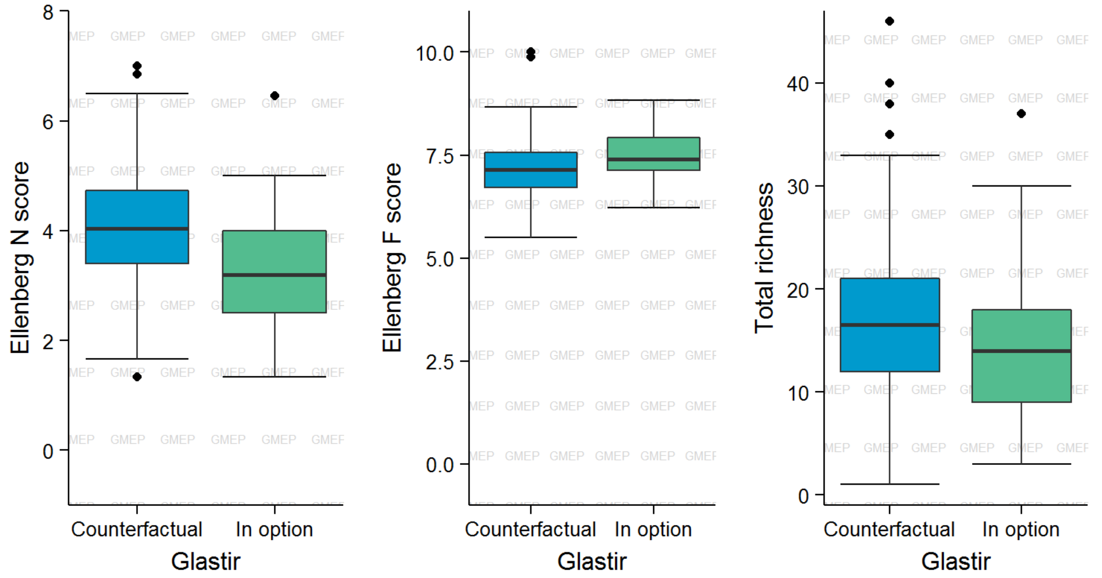
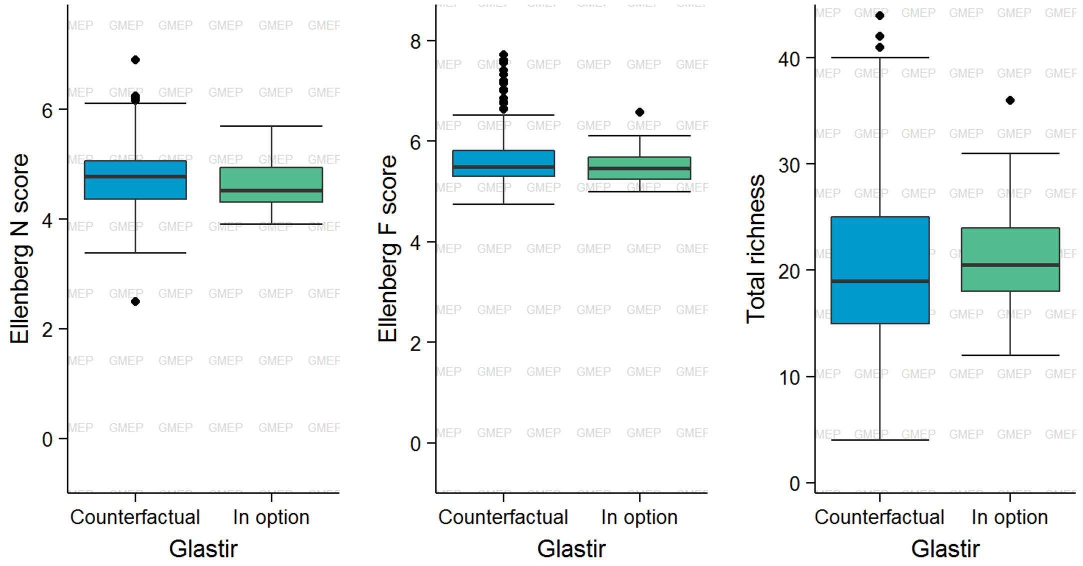


Figure 5: Neutral grassland in option versus out of scheme.



Data:
CSV supplied.

Methodology:
<u>Gmep field survey datasets:</u>
Options with sufficient coincident vegetation plot data for analysis all focussed on management of semi-natural habitats including grazed permanent pasture (15) existing hay-meadow (22), lowland marshy grassland (19) and open country (41a). Plots were assembled from in-option and out of scheme land and grouped by broad habitat for like-with-like comparison.

<u>Indicators:</u>
Mean Ellenberg N score and Ellenberg F score were used as plant species-based indicators of fertility and soil wetness respectively.

<u>Caveats:</u>
Gmep does not record bats. In addition bat populations coincide with few of the Gmep squares. Analysis therefore focusses on detecting the expected impact of options linked to LHB on ecological conditions within each habitat rather than impacts on the target species.

Marsh Fritillary; habitat condition indicators

Target: *Biodiversity*

Question type: *Benefit of Glastir measures*

Question: *What is the impact of the Glastir options on ecological conditions associated with the Marsh Fritillary butterfly (MF)?*

Background to question:
Glastir targets management on named rare species. These are listed in Section 42 of the Natural Environment & Rural Communities Act 2006. The targeting mechanism involves funding bundles of options within areas known to encompass target species populations. Most options are however not species-specific and can be funded in any eligible area of habitat because of the wider benefits they bring. While no benefit is likely to arise for the species in areas where it is absent or unlikely to establish in the future it is useful to determine whether the option results in the desired impact on ecological condition (vegetation and habitat structure, plant species composition, soils and waters) that would directly favour the target species if the option land coincided with species occurrence. This question can be answered using all areas of in-option land without the rare species being present. In most cases Gmep does not measure rare species' performance but focusses on assessing the impact of the option on ecological conditions. In parallel current distribution data is used to say how many recent records for the species coincide with Gmep squares with relevant option uptake.

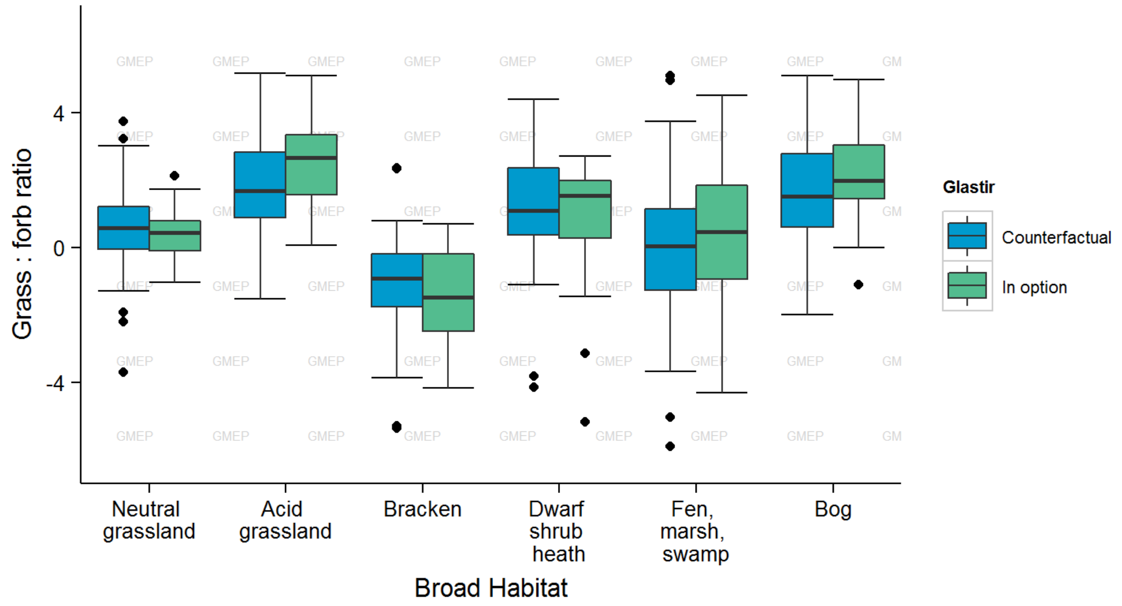
Evidence:
Glastir uptake: Of 27 MF options 12 occur in Gmep squares. The most common options focus on zero or low input grazing of open country, permanent pasture and lowland marshy grassland. Because these option are relatively extensive, a satisfactorily large number of vegetation plots were selected for comparing in-option (n=238) and out of scheme (n=874) land.

Coincidence with target species:
In the 69 Gmep squares with MF options present, 6 had a post-2000 recorded occurrence of Marsh Fritillary (UKBMS data). MF was not recorded in any Gmep square during the 2013/'14 pollinator surveys.

Indicators:
Occurrences of the MF larval foodplant Devil's-bit Scabious (*Succisa pratensis*) were too few to analyse. Plants of wet conditions were significantly more common in Fen, Marsh & Swamp in-option land in area plots away from linear features (Fig1a). Linear plots within the in-option Bog broad habitat were significantly grassier than out of scheme (Fig 1b). Over time the wetness indicator and butterfly foodplant cover would be expected to increase or remain stable and the grass:forb ratio to remain stable or decrease in comparison with out of scheme habitat.

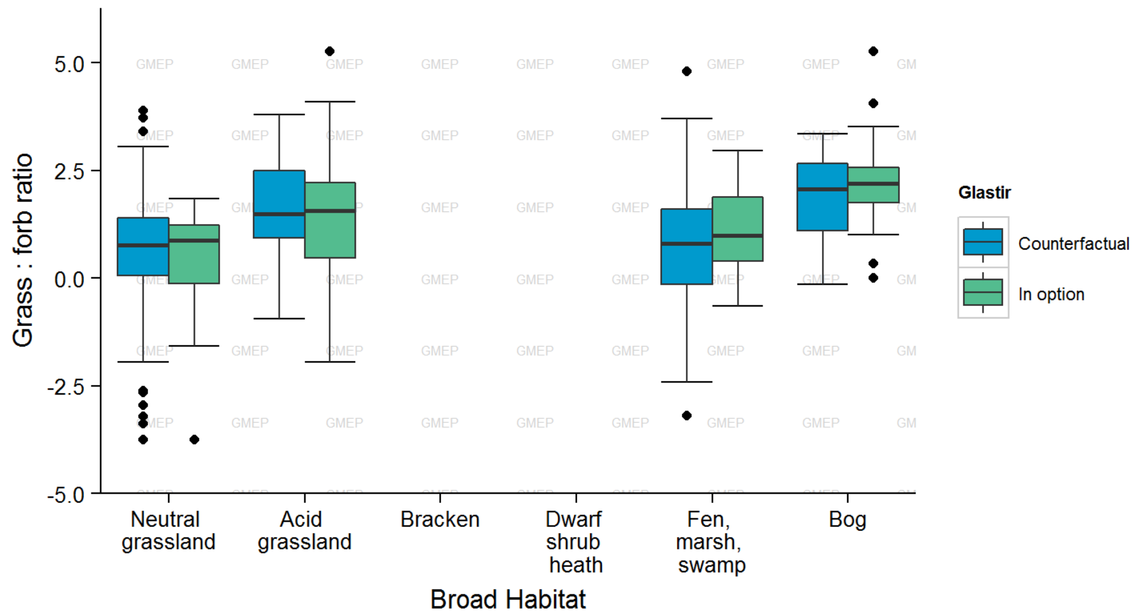
Figure 1: Comparison of area plots (a,c) and linear plots (b,d) in MF options in Gmep squares (2013/'14) with out of scheme plots. Two variables are shown indicating the ratio of cover of grasses to forbs (a,b) and the presence of moisture-loving plants (c,d).

a)



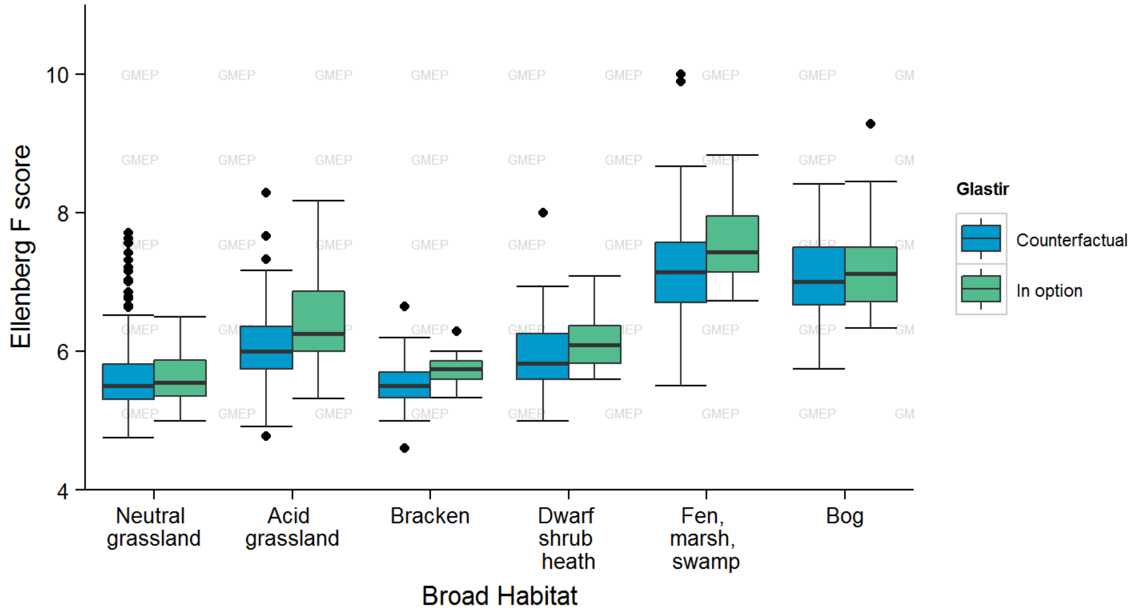
Grass : forb ratio
4
0
-4
Neutral grassland
Acid grassland
Bracken
Dwarf shrub heath
Fen, marsh, swamp
Bog
Broad Habitat
Glastir
Counterfactual
In option

b)

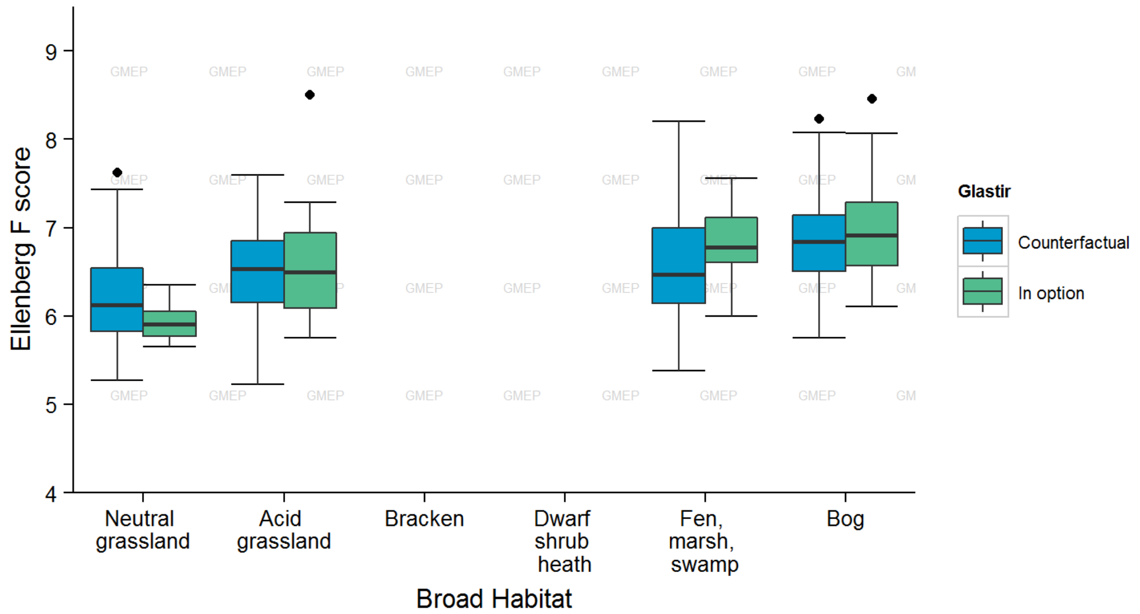


Grass : forb ratio
5.0
2.5
0.0
-2.5
-5.0
Neutral grassland
Acid grassland
Bracken
Dwarf shrub heath
Fen, marsh, swamp
Bog
Broad Habitat
Glastir
Counterfactual
In option

c)



d)



Data:
CSV supplied.

Methodology:
Gmep field survey datasets:
Relatively large numbers of in-option plots allowed analysis by plot type (areal versus linear) and broad habitat thus allowing a like with like comparison between in-option and out of scheme habitat.

Indicators:

Indicator variables were selected as those best able to convey the impact of the options on ecological conditions important for the target species; in this case foodplant abundance, wet conditions and no increase in grass dominance relative to forbs.

Nectar plant abundance

Target: *Biodiversity*

Question type: *Benefit of Glastir measures*

Question: *What is the impact of Glastir on the cover of preferred nectar plants?*

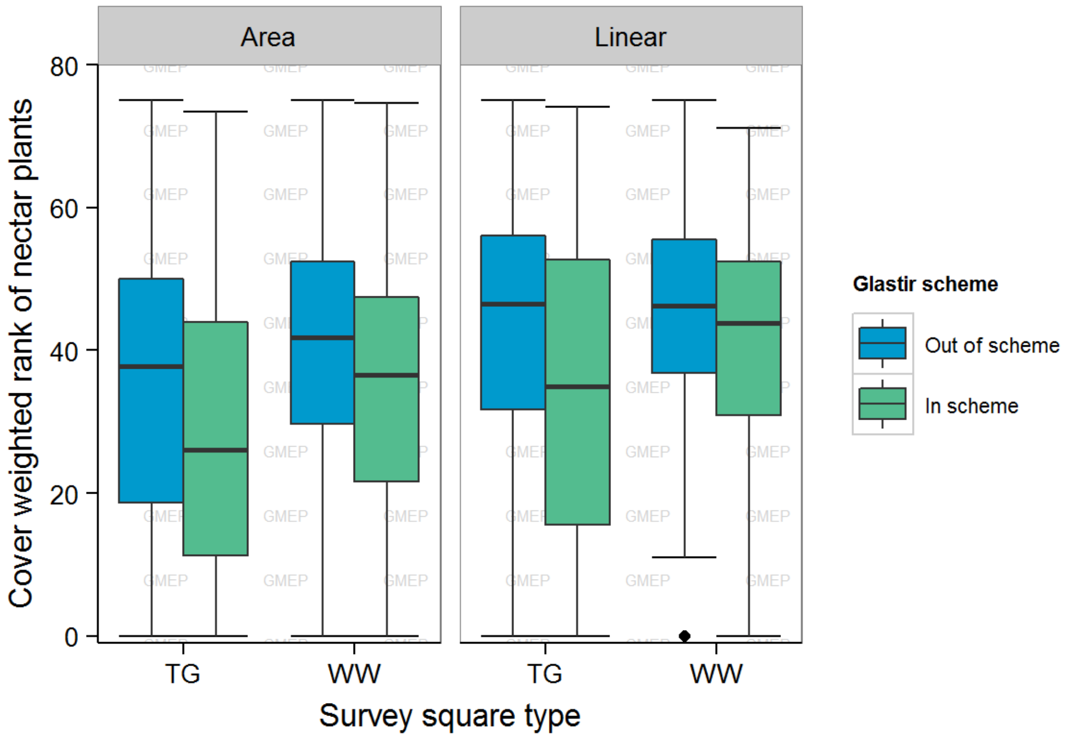
Background to question:

Pollinating invertebrates and their wild nectar plants have declined across NW Europe since around the 1950s. In many places this has led to a pollinator deficit reducing potential supply of the ecosystem service of crop pollination and reducing the biodiversity of nectar plants and their pollinating insects. Over time GMEP survey data can be used to quantify changes in abundance of preferred nectar plants and pollinating insects. However, to correctly interpret observed ecological changes over time it is important to characterise baseline differences between land in and out of Glastir. Therefore differences are presented for cover of preferred nectar plants either in or out of agreement land and by Wider-Wales (WW) and Targeted (TG) squares.

Evidence:

Cover-weighted values of nectar plant importance ranged widely reflecting the inclusion of the full range of habitat types surveyed. The indicator did not differ significantly between in-Glastir and out-of-Glastir land. Over time the broadly extensifying effect of Glastir might be expected to increase values of the indicator. However, the nectar plant list includes species that vary greatly in terms of their preference for disturbance levels and productivity. Therefore in future, separation by habitat could prove a more effective means of discriminating Glastir effects on nectar plants that differ in susceptibility to land management change.

Figure 1: Cover-weighted importance index of preferred nectar plants in GMEP plots combining 2013/’14 field survey data. All broad habitats are included. Plots were divided into those sampling linear features and fields, woods and unenclosed land away from linear features.



Data: *CSV supplied.*
Methodology: GMEP survey datasets: To provide the broadest possible picture of the baseline, GMEP vegetation plots were selected from all habitat types surveyed in 2013 and ’14. Plots were divided into an area group that sample fields, woodlands and unenclosed land and a linear group sampling hedgerows, watercourse banks and field boundaries. Indicators: The indicator was calculated by first ranking the preferred foodplants listed in Dyer, R et al (2014). *The Identification of Preferential Foodplants for Pollinator Species of Concern in the UK. Report to Natural England*. The attribute used to rank each species was the total number of observed pollinator-plant interactions. The highest ranking species were Bramble (*Rubus fruticosus* agg.), Ragwort (*Senecio jacobaea*) and Hogweed (*Heracleum sphondylium*). The mean rank of the species in each GMEP plot was then derived and the importance of the species additionally weighted by its observed cover so that high ranking plants with greater cover result in higher values of the indicator.

Indicators of high and low habitat quality; Common Standards Monitoring plant species

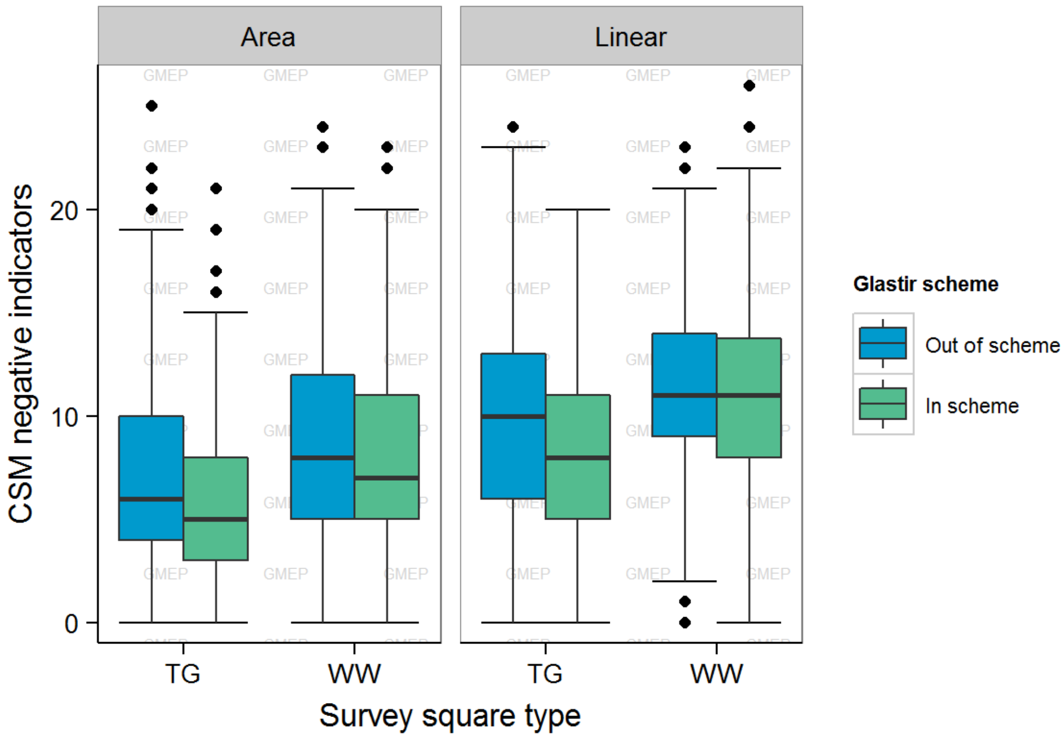
Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: *What is the impact of Glastir on the diversity of species indicating high or low quality habitat?*
Background to question: The ecological condition and extent of most semi-natural habitats has declined in Britain since the 1950s. Since the late 1980s, agri-environment schemes have become an important mechanism for restoration and maintenance of agriculturally managed habitats. The Glastir scheme pays land owners for production foregone as a result of implementing a broadly extensifying series of management options. As a result, biodiversity of species associated with 'good' habitat condition, as defined by the statutory conservation agencies, should be maintained or increase in number. Over time GMEP survey data can be used to measure such changes. To correctly interpret observed ecological changes over time it is important to first characterise baseline differences between land in and out of Glastir agreement land. Counts of JNCC Common Standards Monitoring (CSM) species per vegetation plot are used as an overall indicator of conservation value. Differences are also presented by Wider-Wales (WW) and Targeted (TG) squares.

Evidence:

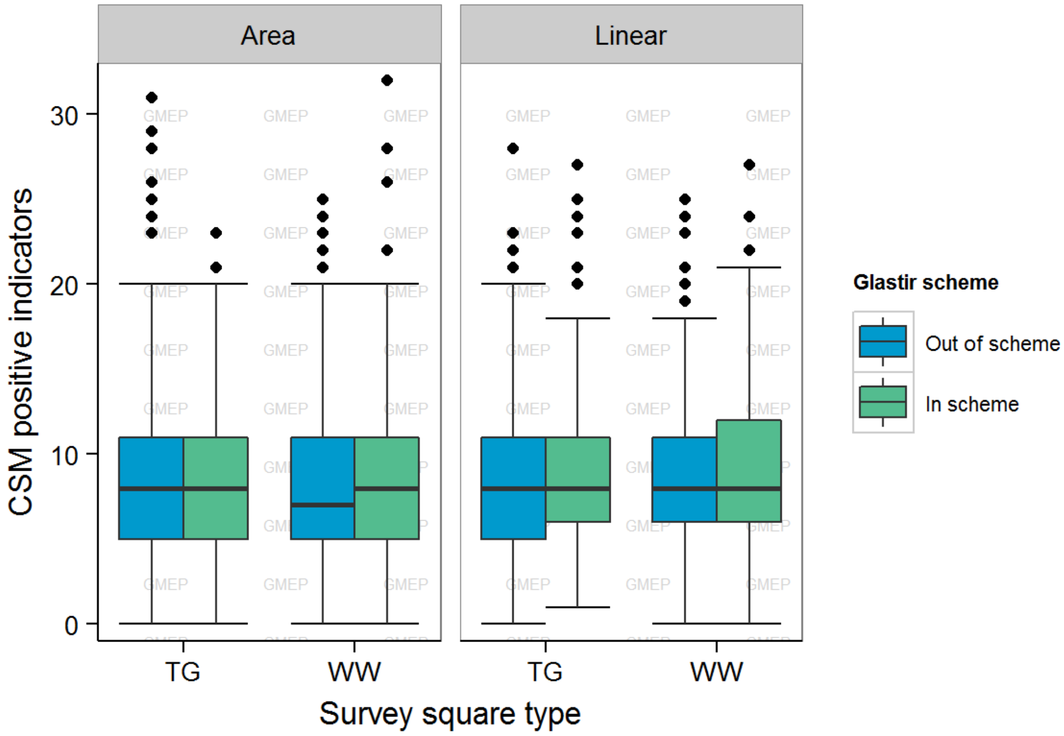
CSM species richness did not differ between land in and out of Glastir in 2013 and '14.

Figure 1: Count of a) negative and b) positive CSM indicator species per vegetation plot. Data for 2013 and '14 were combined and all broad habitats are included. Plots were divided into linear plots sampling linear features and area plots sampling fields, woods and unenclosed land away from linear features.

a)



b)



Data:

CSV supplied.

Methodology:

GMEP field survey datasets:

To provide the broadest possible picture of the baseline, plots were selected from all habitat types and divided into an area group sampling fields, woodlands and unenclosed land and a linear group sampling hedgerows, watercourse banks and field boundaries.

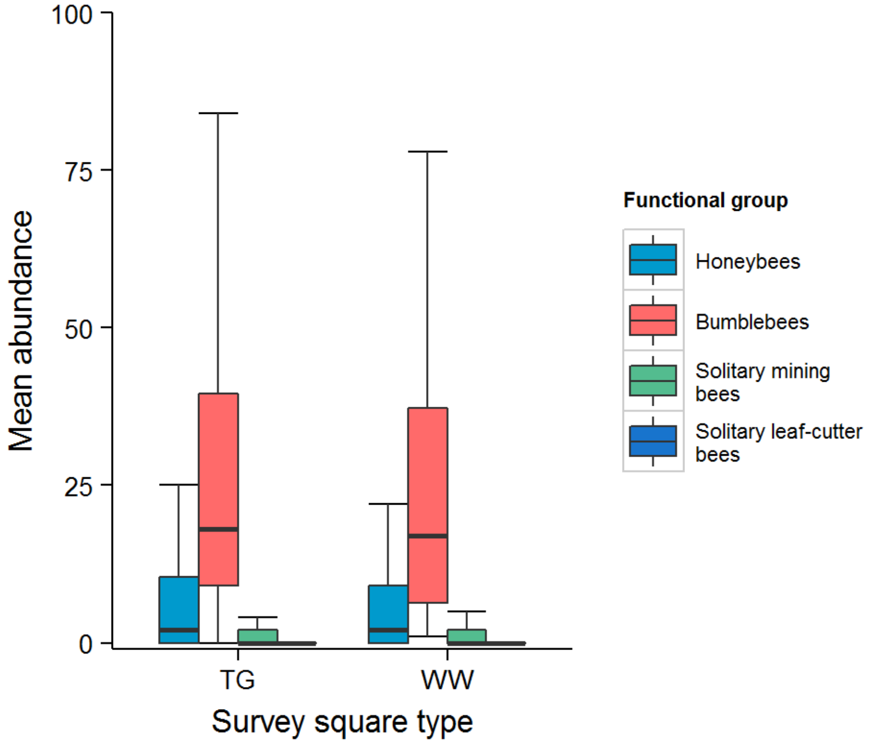
Indicator:

The total number of CSM indicators in each vegetation plot was counted. Negative indicators (poor condition) were counted separately from positive indicators (good condition). Species were extracted from a list compiled from JNCC CSM Guidance documents by the Botanical Society of the British Isles in March 2014.

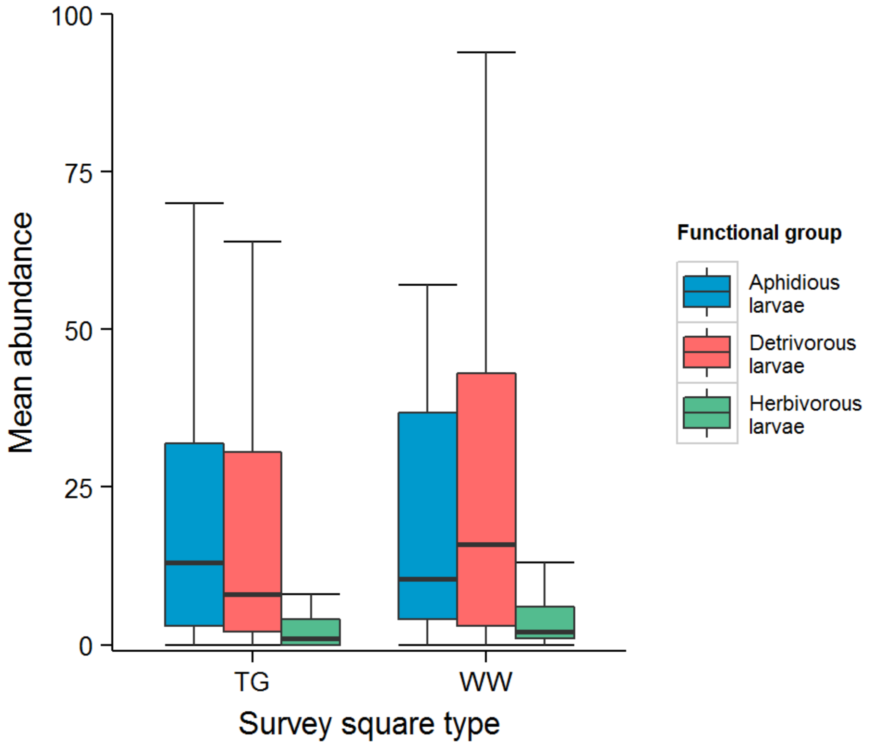
CSM indicator counts in each plot were **not** restricted to those applying just to the sampled habitat type. For example if a plot sampled neutral grassland then all species were counted not just those applying to neutral grassland habitats. This approach has several merits; it is consistent with deriving an overall indicator of the biodiversity of conservation indicator species in the countryside, it allows the indicator to be expressed for habitats without published lists such as linear features and woodlands, it is independent of decisions about the allocation of the plot to habitat type.

Bee and Hoverfly abundance

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question*: How does the baseline distribution of bees and hoverfly species differ between Targeted (TG) and Wider Wales (WW) 1km squares in GMEP?*
Background to question: GMEP is designed to detect the impacts of the Glastir scheme and so a sample of 1km squares is weighted toward land prioritised under the scheme. This results in a Targeted sample of squares that are analysed alongside a Wider Wales set of squares representing an unbiased sample of the 'average' countryside for comparison. To correctly interpret observed ecological changes over time it is important to characterise baseline differences between the two sub-samples. The differences between Targeted and Wider Wales squares are shown for mean abundance of functional groups of hoverflies and bees. These groups are recorded in the GMEP pollinator surveys and differ in the ecosystem services they help to provide. Hoverfly groups are differentiated based on the ecosystem services provided by their larvae: Group1 = pest control, group2 = organic matter decomposition, group 3 = herbivores. Bees are split into 4 functional groups determined by the way in which the females collect pollen, which affects their efficiency as pollinators. Honeybees and bumblebees collect it on specialised hairs on their hind legs, but wet the pollen so its sticks and is less likely to fall off. Bumblebees are much more hairy so pick up more pollen on body hair. Solitary bees all collect dry pollen which is much more likely to fall off and many are hairy. Mining bees collect the pollen on their legs, whilst leaf-cutters collect it on their abdomen.
Evidence: Bee groups were similarly abundant in Targeted (TG) and Wider Wales (WW) squares with bumblebees being by far the most abundant bee group recorded across all squares. Hoverfly groups were generally more abundant in Wider Wales 1km squares, particularly those with detritivorous larvae (group 2). Those with predatory larvae feeding on aphids were more similar in abundance in Targeted and Wider Wales squares. Figure 1. Baseline differences in total counts of pollinating invertebrates per Gmep 1km square in 2013 and 2014; a) Bees, b) Hoverflies. a)



b)



Methodology:

The GMEP pollinator surveys are based on the Wider Countryside Butterfly Survey and suited to recording common and widespread (wider countryside) species. Pollinator surveys focused on three main pollinator groups: butterflies, bees and hoverflies. Butterflies were recorded to species level, whilst bees and hoverflies were recorded as groups based on broad differences morphological and ecological differences. Surveys were split into two independent parts: a standardised 2km transect route through each square followed by a timed search in a 150m^2 flower-rich area within the square. Two visits per square per year are carried out; one in July and a second in August. In total, 60 1km squares were visited in 2013 and 90 in 2014. Surveys were only conducted between 10:00 and 16:00, or between 09:30 and 16:30 if >75% of the survey area was un-shaded and weather conditions were suitable for insect activity. The criteria for suitable weather were: temperature between 11 and 17^{o}C with at least 60% sunshine or above 17^{o}C regardless of sunshine, and with a wind speed below 5 on the Beaufort scale (small trees in leaf sway).

Butterfly diversity and abundance

Target: *Biodiversity*

Question type:*Benefit of Glastir measures*

Question*: How does the baseline distribution of butterfly species differ between Targeted and Wider Wales 1km squares in GMEP?*

Background to question:

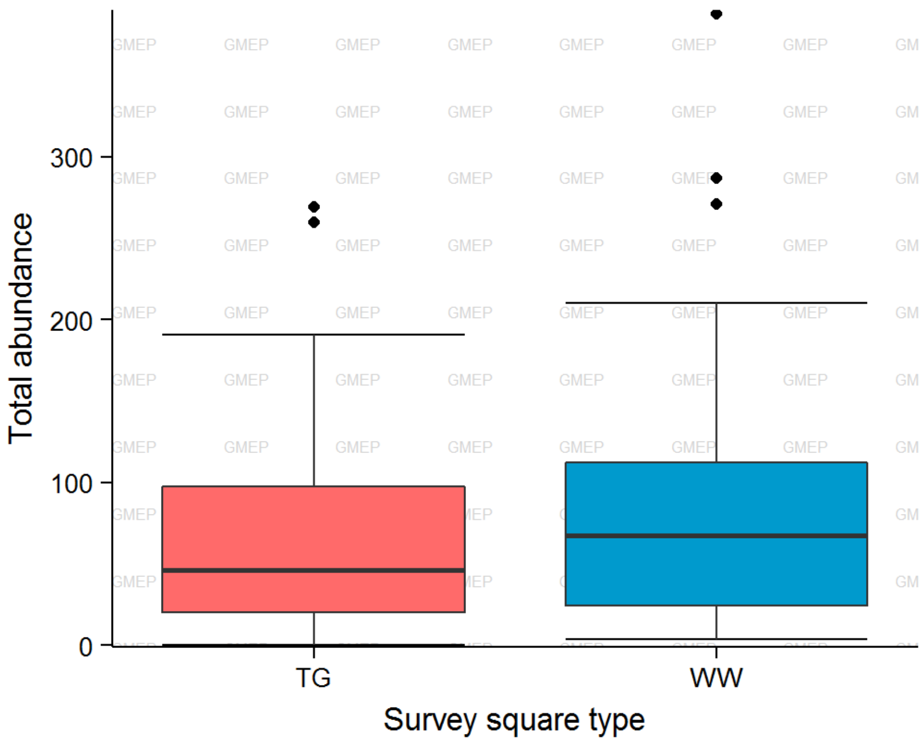
Welsh Government target Glastir funding according to a system of environmental priorities. Currently the focus is on diffuse pollution and climate change and so land that is targeted under these priorities will receive greater funding and therefore greater levels of management intervention. Since the job of GMEP is to detect Glastir impacts, the sample of 1km squares is weighted toward prioritised land resulting in a Targeted (TG) sample of squares that are analysed alongside a Wider Wales (WW) set of squares that represent an unbiased sample of the 'average' countryside for comparison. To correctly interpret changes over time it is important to characterise baseline differences between the two sub-samples. For example the Targeted squares will receive greater levels of funding and so more change is expected to be attributable to Glastir but differences in starting values of biodiversity, soil conditions and land cover will also influence the responsiveness of the two samples over and above differences in intervention. More sophisticated ways of accounting for these differences will be applied as the time series grows and change over time becomes quantifiable. At present it is useful simply to describe the differences between the two sub-samples.

Evidence:

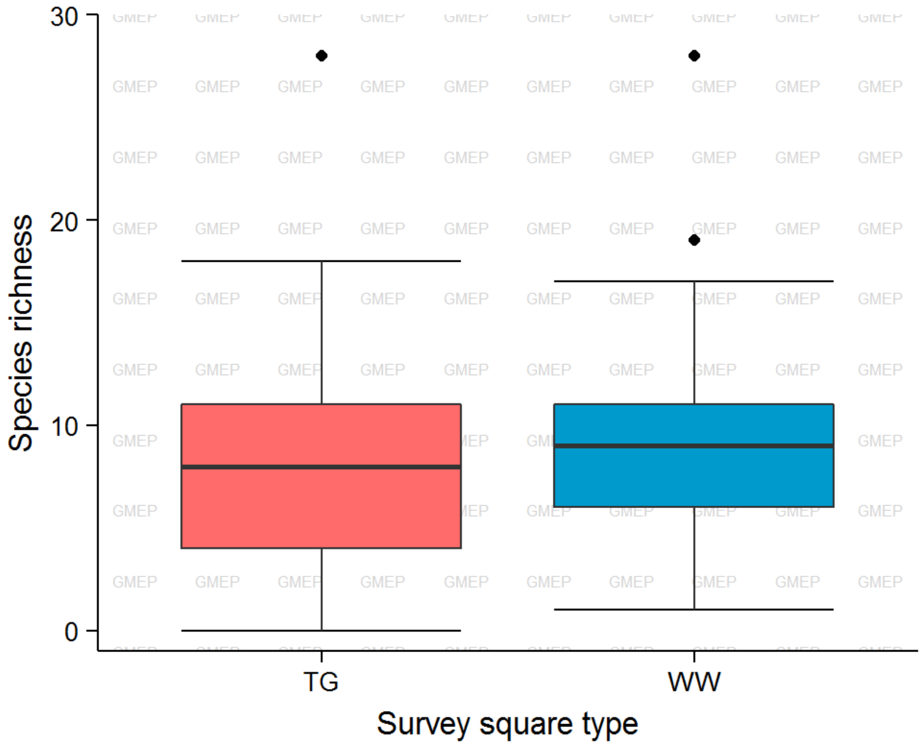
Total counts of butterflies per square (Fig 1a) and butterfly species richness (Fig 1b) were lower in the Targeted sample. This is likely to reflect the more unenclosed and upland nature of the habitats in the sample, which was weighted toward bog and heath.

Figure 1. Total counts of butterflies (a) and butterfly species richness (b) in GMEP Targeted (TG) or Wider Wales (WW) squares from pollinator surveys carried out in 2013 and 2014.

a)



b)



Methodology:
The GMEP pollinator surveys are based on the Wider Countryside Butterfly Survey (WCBS) and are suited to recording common and widespread (wider countryside) species. Pollinator surveys focused on three main pollinator groups: butterflies, bees and hoverflies. Butterflies were recorded to species level, whilst bees and hoverflies were recorded as groups based on broad morphological and ecological differences. Surveys were split into two independent parts: a standardised 2km transect route through each 1km^2 followed by a timed search in a 150m^2 flower-rich area within the square. Two visits per square per year are carried out; one in July and a second in August. In total, 60 1km squares were visited in 2013 and 90 in 2014. Weather criterion: surveys were only conducted between 10:00 and 16:00, or between 09:30 and 16:30 if >75% of the survey area was un-shaded and weather conditions were suitable for insect activity. The criteria for suitable weather were: temperature between 11 and 17°C with at least 60% sunshine or above 17°C regardless of sunshine, and with a wind speed below 5 on the Beaufort scale (small trees in leaf sway).

Whole Farm Code and eutrophication indicators on agreement land

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: *Has the Whole Farm code prevented eutrophication of semi-natural habitats on agreement land?*
Background to question: Farms in the Glastir scheme are subject to the Whole Farm Code. This includes rules applicable to so-called 'habitat land' that has not been subject to agricultural improvement. The application of fertilisers is prohibited on such land under the code. The objective is to "..help retain our native Welsh vegetation types, plants and animals." A large body of evidence shows that improvement from increased fertiliser application favours a smaller number of agriculturally favoured species, often grasses, at the expense of a larger number of native species more suited to less productive conditions, often forbs. The successful prevention of improvement on existing 'habitat land' under the Whole Farm Code should therefore result in maintenance or increased abundance of typical forbs relative to grasses and no long-term decline in plant species associated with higher conservation value of unimproved habitats. A series of plant and soil indicators are used for this purpose. In order to best interpret expected future changes it is important to show how these indicators vary between lands in and out of Glastir at the start of the scheme.
Evidence: <u>Phosphorus in soil:</u> High available levels of this nutrient are associated with agricultural grasslands. The higher Olsen's P on agreement land in Wider Wales squares may simply reflect the greater targeting of Glastir on grassland-dominated farmland while lower P levels on agreement land in Targeted squares probably reflect the greater abundance of peaty upland habitats targeted for Glastir options (Fig 1). <u>Plant species composition:</u> Indicators of qood quality habitat were equally common in and out of scheme and in Targeted and Wider-Wales (Fig 3). However, in-scheme 'habitat land' is associated with vegetation indicating lower productivity and with fewer negative conservation indicator species (Fig 4) despite being grassier, although not significantly so (Fig 5). Targeted squares are separated again from Wider Wales being more likely to include low productivity peaty habitats, and hence having lower fertility scores (Fig 5), and supporting fewer agriculturally favoured species that indicate lower conservation value of 'habitat land' (Fig 4). Figure 1: Olsens P in soil sampled from 'habitat land' in or out of Glastir agreement in 2013 and '14.

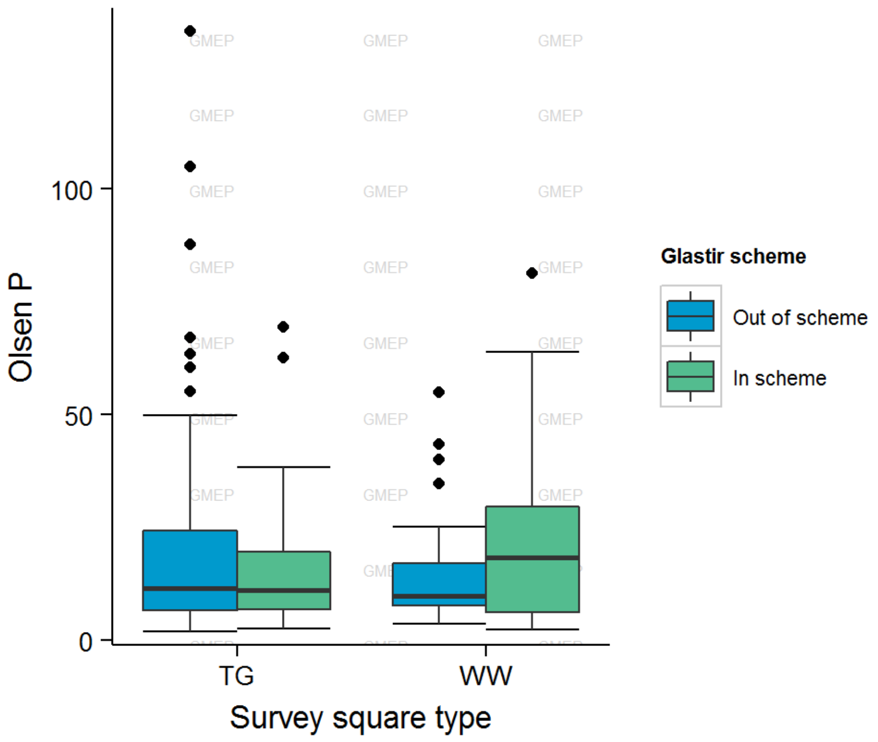


Figure 2: Count of Common Standards Monitoring (-ve) plant species in plots in ‘habitat land’.

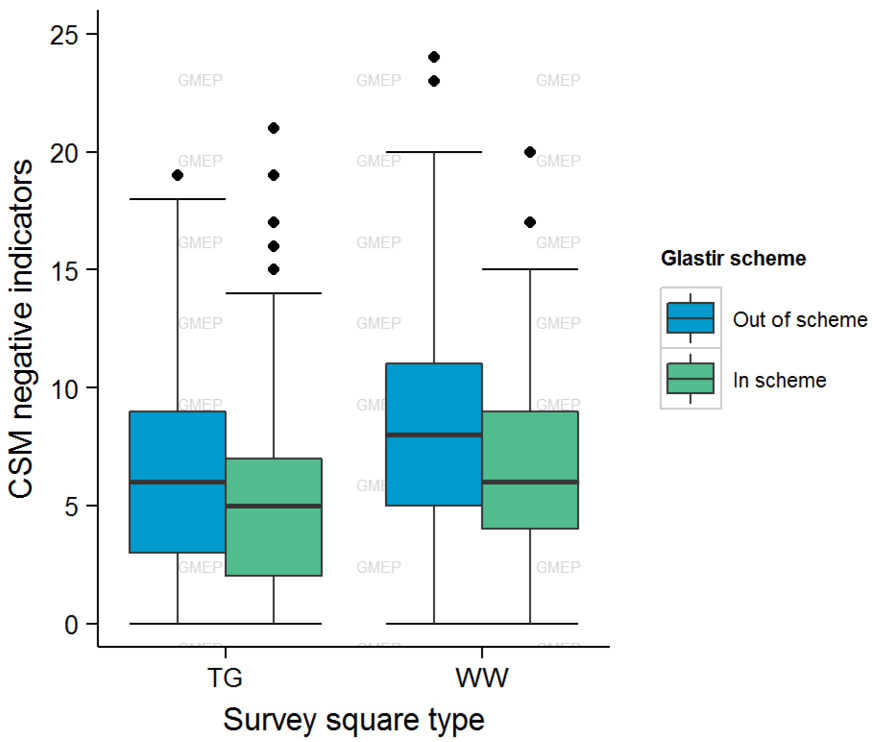


Figure 3: Count of Common Standards Monitoring (+ve) plant species in plots in ‘habitat land’.

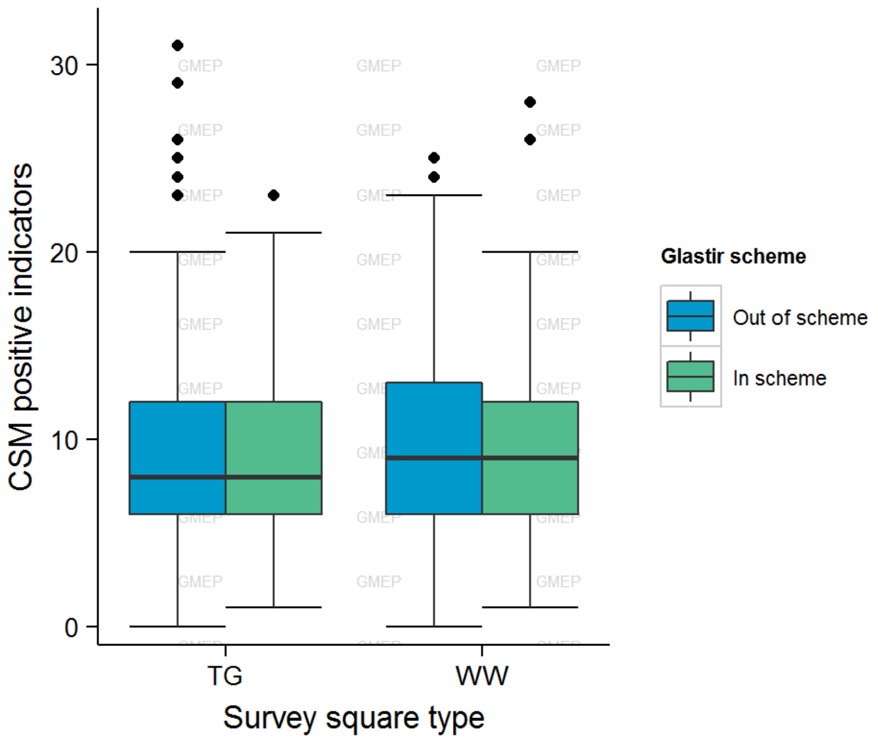


Figure 4: Ratio of grass to forb cover in plots in ‘habitat land’.

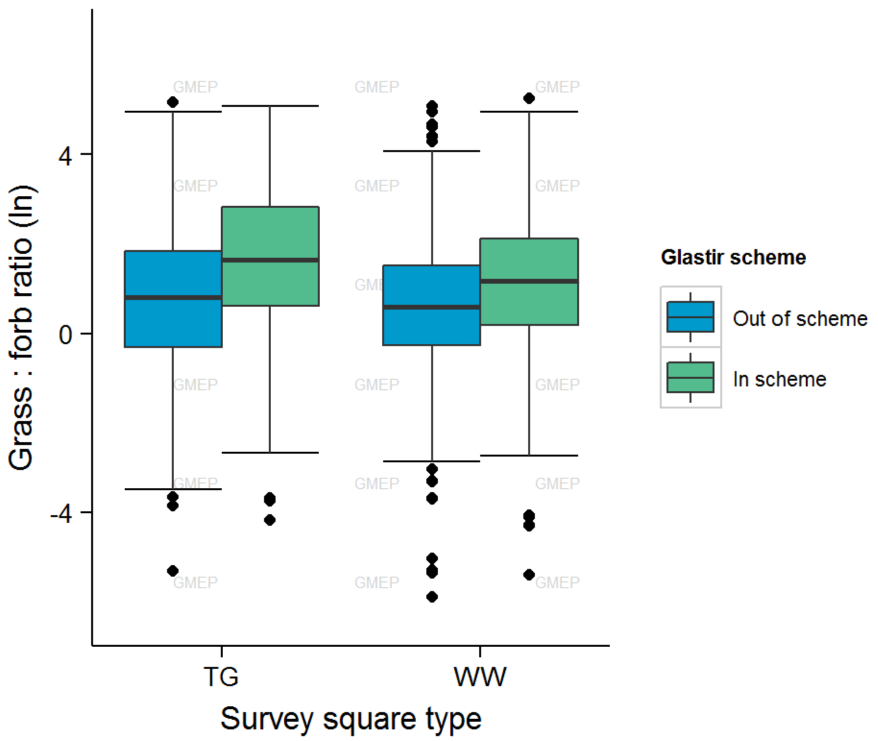
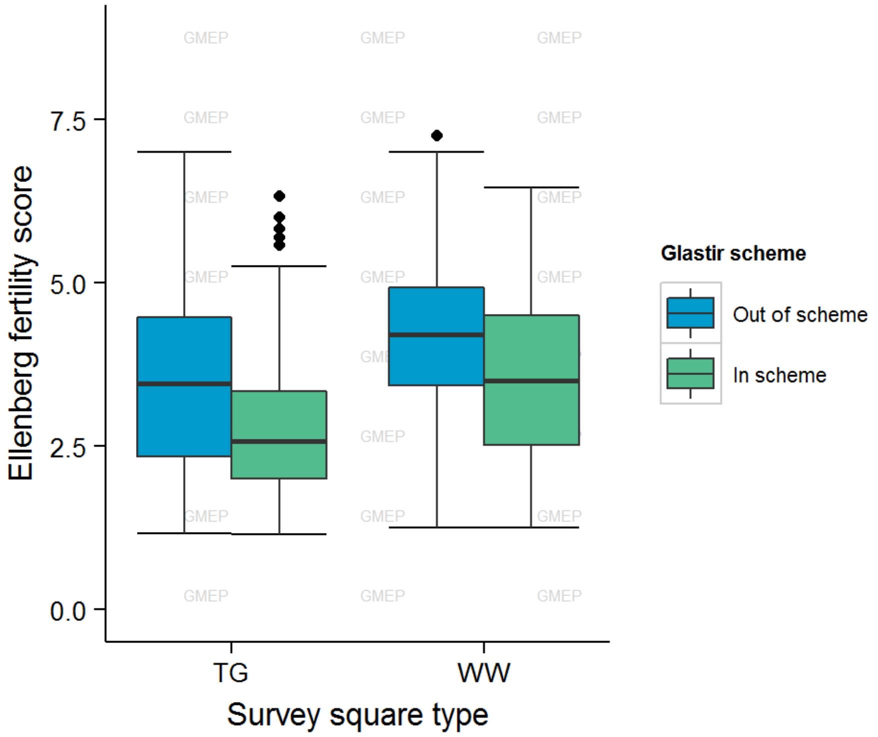


Figure 5: Index of vegetation fertility based on plant species in plots in ‘habitat land’.



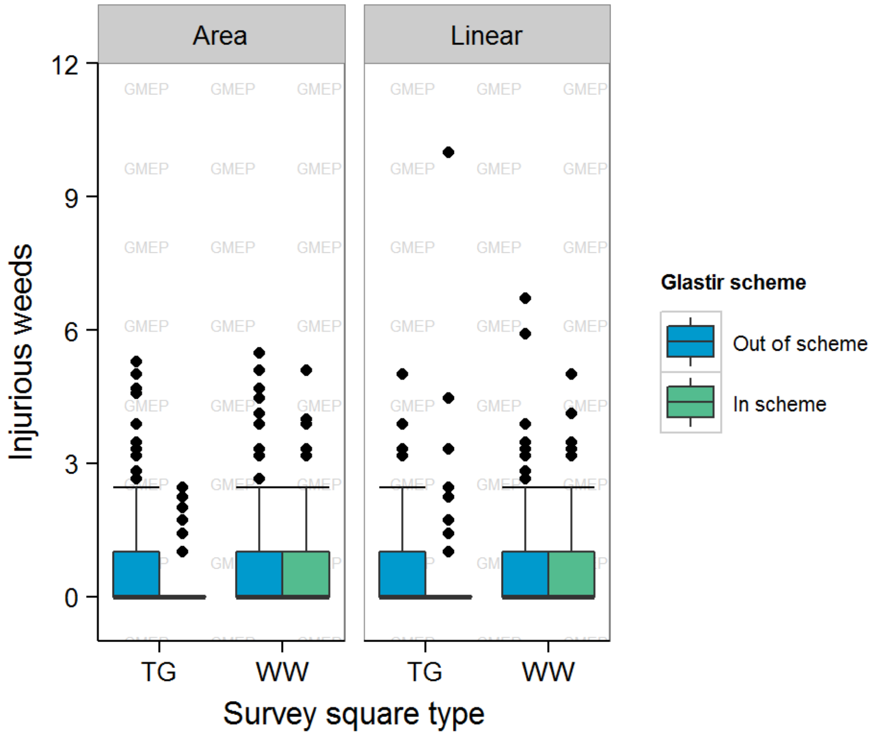
Data:
Significant differences between in and out-scheme land applied to count of negative CSM indicator species only.

CSV supplied.

Methodology:
Gmep field survey datasets:
'Habitat land' was defined as all plots with <25% combined cover of *Lolium* spp and *Trifolium repens*. Woodland, arable, urban, open water and littoral broad habitats were excluded. Vegetation plots were selected focussing on areal habitat only; linear features were excluded. Plots were defined as 'in-scheme' if they fell within Glastir agreement boundaries provided by WG. All data for 2013 and 2014 were combined.

Derived indicators:
See soils portal pages for soil sampling protocols. Plant species-based indicators were all derived from the species composition and cover recorded in each vegetation sampling plot. Common Standards Monitoring indicators were extracted from a list compiled by the Botanical Society of the British Isles in March 2014 from published agency guidance notes. Mean Ellenberg fertility and grass:forb ratio were calculated using methods from Countryside Survey (www.countrysidesurvey.org.uk).

Whole Farm Code; abundance of Invasive Non-Native Species and Injurious Weeds

Target: *Biodiversity*
Question type: *Benefit of Glastir measures*
Question: *What is the impact of the Glastir Whole Farm Code on abundance of Invasive Non-Native Species (INNS) and Injurious Weeds?*
Background to question: Farms in the Glastir scheme are subject to the Whole Farm Code. The application of herbicides is prohibited except for spot treatment of invasive plants and injurious weeds. These species are important to control because they can reduce agricultural productivity, act as sources for dispersal to surrounding land, damage buildings and ancient monuments, and invade habitats and waterways to the detriment of native wildlife. The Whole Farm Code restricts herbicide use but in doing so should not favour weed establishment and dispersal. Results show the baseline cover of INNS and Injurious Weed species in vegetation plots in or out of agreement land and covering all areal habitats and linear features in the 2013/'14 surveys.
Evidence: INNS records were too few in Gmep plots to support plotting and analysis. Injurious Weed cover did not differ significantly between in and out-scheme land (Fig 1). Figure 1: Summed square-root transformed cover of Injurious Weeds in Gmep plots from all surveyed habitat areas and linear features in Gmep squares. 
Data: *CSV supplied.*
Methodology: <u>GMEP field survey datasets:</u>

Linear and areal plots were selected from Gmep 1km square field survey data covering all habitats surveyed.

Indicators:
Recorded cover was summed in each plot for the INNS species Japanese Knotweed, Himalayan Balsam and Giant Hogweed. A separate indicator was similarly derived for the notifiable Injurious Weeds Creeping Thistle (*Cirsium arvense*), Spear Thistle (*Cirsium vulgare*), Broad-leaved Dock (*Rumex obtusifolius*), Curled Dock (*Rumex crispus*) and Ragwort (*Senecio jacobaea*) (see Defra Report WC1042 (2013)).

Appendix 5.11: Biodiversity – data portal entries

Headline question: What are the long term trends in the condition of priority (section 42) habitats?

Blanket Bog

Background

Blanket bogs are a section 42/priority habitat consisting of rain-fed extensive bog communities or landscapes with poor surface drainage typically forming in upland areas with high rainfall. They are waterlogged peat forming habitats, containing peat-forming plants e.g. heather, Sphagnum, cotton grasses, sundews that are adapted to wet environments. Peat depths can be quite variable ranging from 0.5m- 3m. There are extensive areas of Blanket Bog in the Welsh uplands and they are important habitats for characteristic and rare species (e.g. cloudberry) and for carbon sequestration and storage. Threats to Blanket Bogs include drainage, burning, overgrazing and cutting peat for fuel or garden uses, climate change and atmospheric pollutants. The condition of Blanket Bog can be measured in a number of different ways. Here we show changes in the number of characteristic bog species, total plant species richness, plant preference scores for moisture and soil Carbon. There are other measurements taken in GMEP that could also be used.

Methodology

As part of the field survey in 2013 and 2014 permanent vegetation plots were established. These include random plots (200^2m) and 2m x 2m plots in Blanket Bog. Within the plots all higher plants were recorded to species level and a limited number of lower plants. Using the vegetation plot data a number of indicators have been calculated to report on habitat condition. The total number of species within a plot has been calculated. The number of Common Standard Monitoring indicator species was calculated by taking species identified in the guidance for the priority habitat (JNCC) and in discussions with the Botanical Society of the British Isles and identifying characteristic Bog indicators. The number of CSM species within a plot was then calculated. Data from Countryside Survey in 1990, 1998 and 2007 has been used for the long term trend. Soil data from soil cores taken at the 200m^2 plots has also been used to calculate an indicator for soil carbon. A better indicator for carbon content of blanket bog soils might be topsoil bulk density, however, we only have data back to CS2007 for this measure.
There has been a slight decrease in the number of characteristic Bog species (CSM indicators) between 1990 and 1998 (Figure 1, Table 1), the GMEP Wider Wales sample has a higher number of indicators to CS in 2007 with slightly more in the targeted squares.
There has been a decline in overall species richness in Blanket Bogs since 1990 in 2m x 2m and 200m2 plots (Figure 2, Table 2); however the GMEP sample is not significantly different than in 2007.
The only significant difference between years in changes in sphagnum cover is between 2007 and the GMEP sample in 2m x 2m plots.
There was a significant increase in Eriophorum vaginatum cover in 200m2 plots between 1990 and 2007
There was a significant increase in the cover of Dwarf Shrubs between 1998 and 2014 in 2m x 2m plots, changes between other years were not significant.
There were no significant changes in Ellenberg Moisture values.
The trend in concentration of topsoil carbon is for a slight increase since 1978 which can be seen in Figure 3 and Table 3.

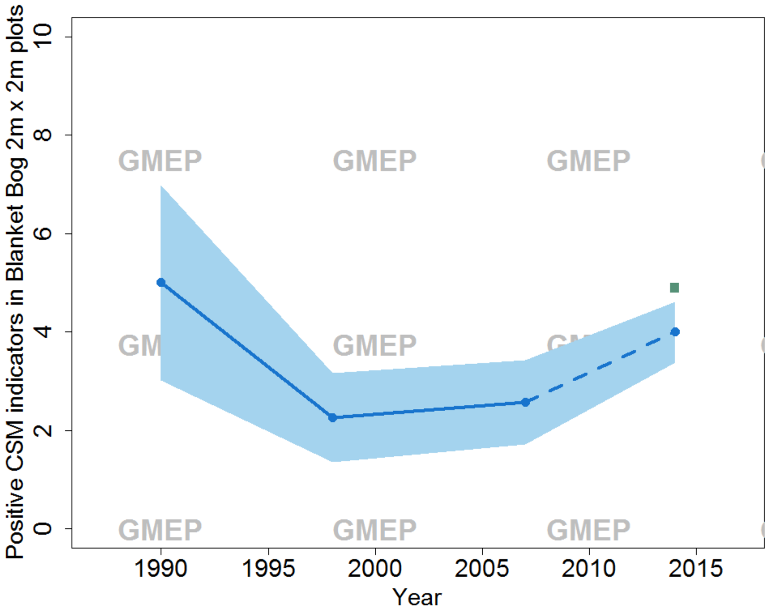


Figure 1: Trends in the mean number of characteristic Blanket Bog species (CSM) in 2m x 2m plots (same pattern in 200m2 plots)

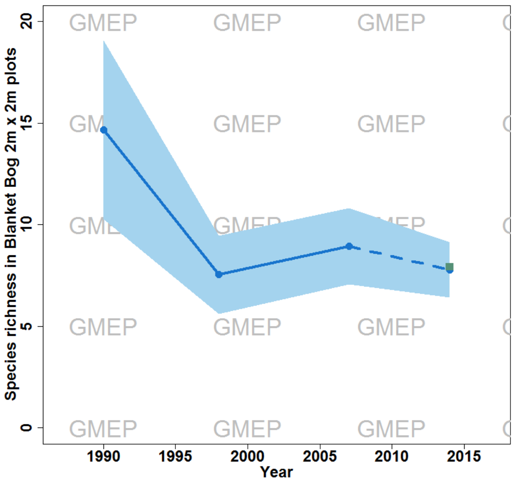


Figure 2a: Trends in the mean Total plant species richness in 2m x 2m plots

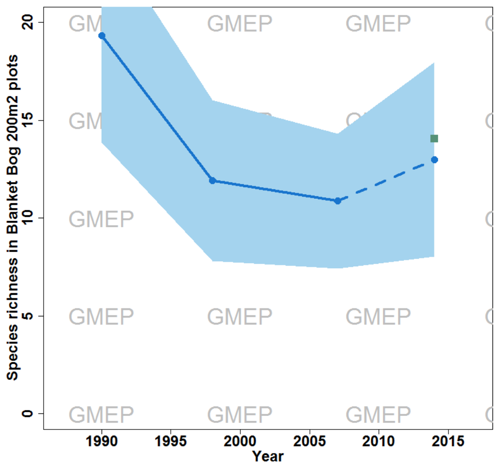


Figure 2b: Trends in the mean Total plant species richness in 200m2plots

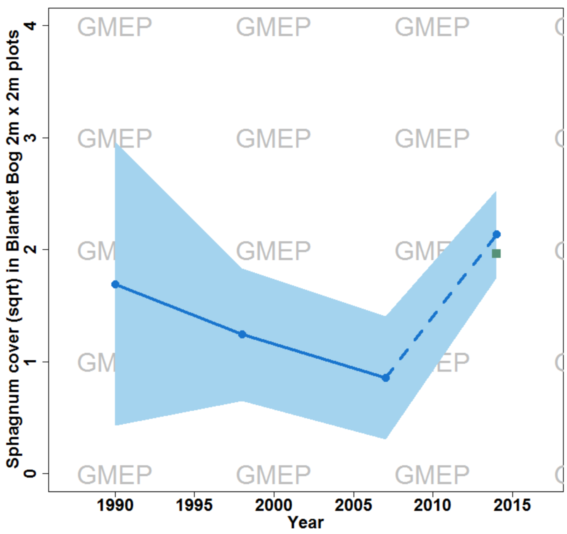


Figure 3a: Trends in the mean cover of Sphagnum in 2m x 2m plots

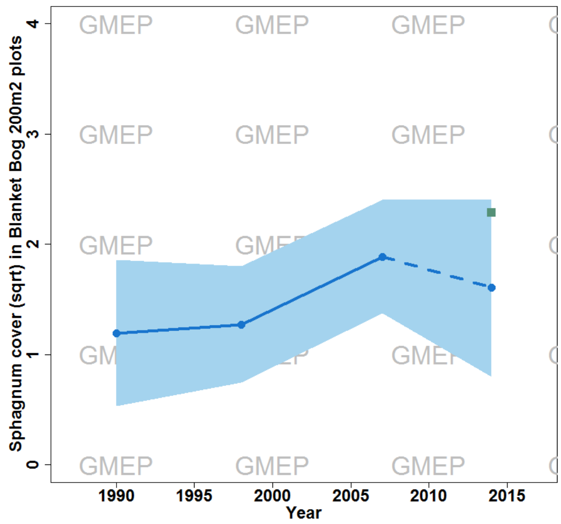


Figure 3b: Trends in the mean cover of Sphagnum in 200m2 plots

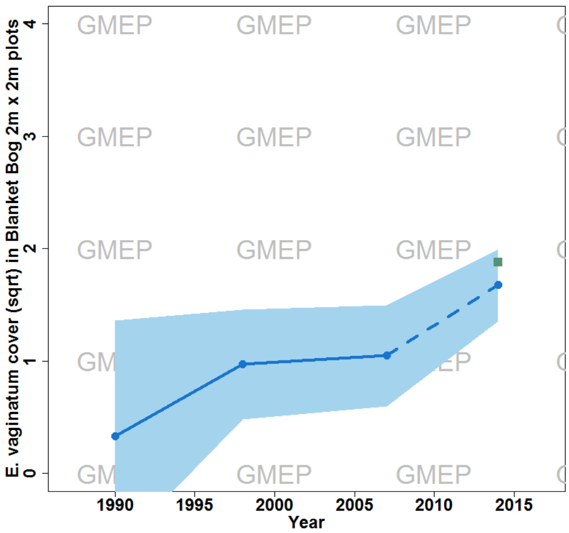


Figure 4a: Trends in the mean cover of *E.vaginatum* in 2m x 2m plots

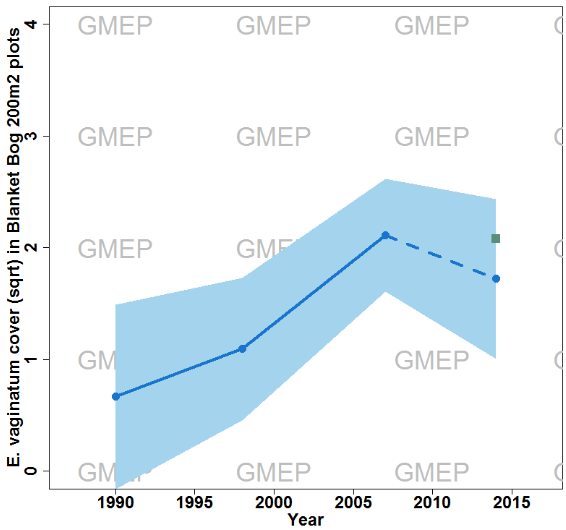


Figure 4b: Trends in the mean cover of *E.vaginatum* in 200m2 plots

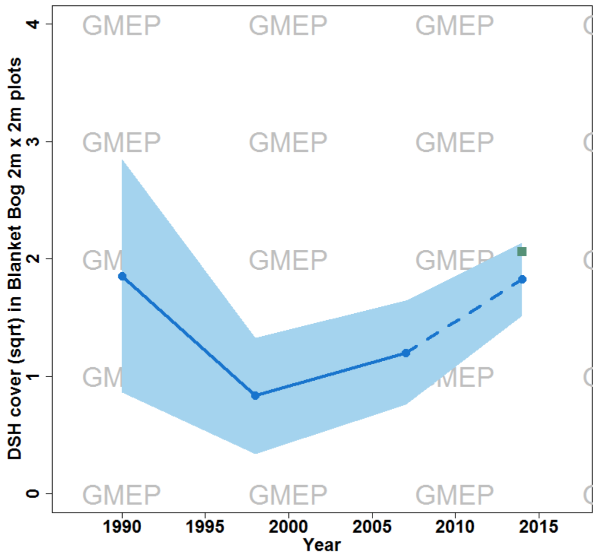


Figure 5a: Trends in the mean cover of *Dwarf Shrubs* in 2m x 2m plots

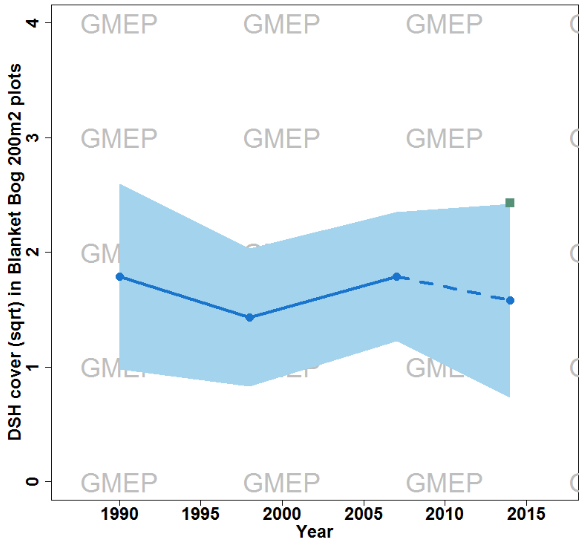


Figure 5b: Trends in the mean cover of *Dwarf Shrubs* in 200m2 plots

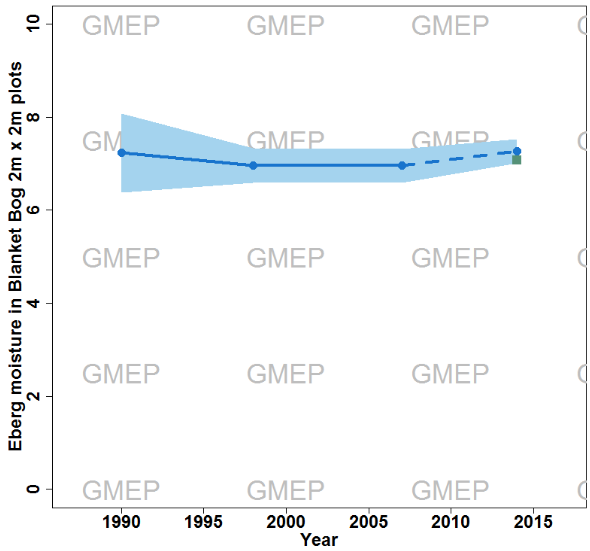


Figure 6a: Trends in Ellenberg moisture score in 2m x 2m plots

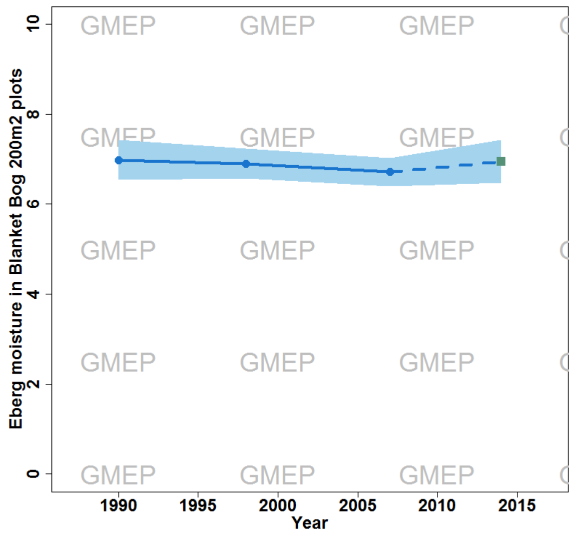


Figure 6b: Trends in Ellenberg moisture score in 200m2 plots

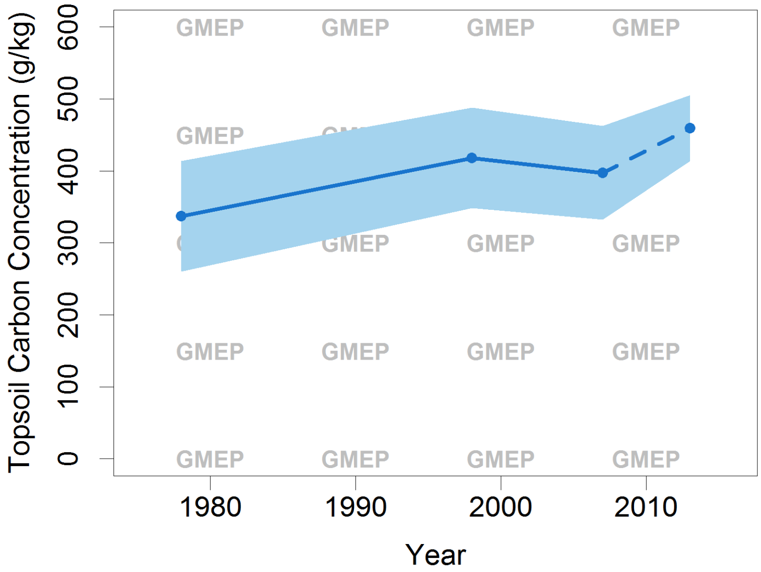


Figure 7: Changes in Topsoil carbon concentration

Table 1: Trends in the mean number of Characteristic Bog species (CSM) in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990: CS	5.00	3.02	6.98
1998: CS	2.26	1.36	3.17
2007: CS	2.57	1.72	3.43
2013/14: GMEP	4.00	3.39	4.61

There has been a slight decline between 1990 and 1998 and a significant difference between 2007 and 2013/14

Table 2a: Trends in the mean total species richness per 2m x 2m plot

Year	Estimated_Value	Lower_est.	Upper_est.
1990	14.67	10.28	19.05
1998	7.54	5.62	9.46
2007	8.94	7.07	10.80
2013/14: GMEP	7.77	6.41	9.14

Changes between 1990, 1998 and 2007 are significant; however there are no significant differences between 2007 and 2014.

Table 2b: Changes in species richness in 200m2 plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	19.32	13.86	24.79
1998	11.92	7.82	16.02
2007	10.88	7.43	14.33
2014	13.00	8.04	17.96

There is a sig decrease between 1990 and 2007

Table 3a: Changes in Sphagnum cover in 2m x 2m plots

Year	N	Estimated_Value	Lower_est.	Upper_est.
1990	3	4.33	0.50	8.16
1998	12	3.07	1.28	4.86
2007	15	2.09	0.42	3.75
2013/14: GMEP	97	5.55	4.36	6.74

There is a significant difference between 2007 and 2013/14 GMEP sample

Table 3b: Changes in Sphagnum cover in 200m2 plots

Year	N	Estimated_Value	Lower_est.	Upper_est.
1990	3	1.85	-0.34	4.05
1998	5	2.16	0.50	3.82
2007	8	3.66	2.09	5.24
2014	39	3.64	1.24	6.04

There are no significant differences

Table 4a: Changes in *E. vaginatum* in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	0.33	-0.69	1.36
1998	0.97	0.48	1.46
2007	1.05	0.60	1.50
2014	1.68	1.36	2.00

There are no significant differences between years

Table 4b: Changes in *E.vaginatum* in 200m2 plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	0.67	-0.16	1.49
1998	1.09	0.45	1.73
2007	2.11	1.61	2.62
2014	1.72	1.01	2.44

There is a significant difference between 1990 and 2007

Table 5a: Changes in Dwarf Shrubs in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	1.86	0.86	2.85
1998	0.84	0.34	1.33
2007	1.20	0.76	1.65
2014	1.83	1.52	2.14

There is a significant difference between 1998 and 2014, changes between other years are not significant

Table 5b: Changes in DSH in 200m2 plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	1.79	0.98	2.59
1998	1.43	0.83	2.03
2007	1.79	1.23	2.35
2014	1.58	0.73	2.42

There are no significant differences between years

Table 6a: Changes in Ellenberg moisture values in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	7.23	6.39	8.07
1998	6.96	6.59	7.33
2007	6.95	6.60	7.31
2014	7.27	7.01	7.54

There are no significant differences between years

Table 6b: Changes in Ellenberg moisture values in 200m2 plots

Year	Estimated_Value	Lower_est.	Upper_est.
1990	6.98	6.54	7.43
1998	6.90	6.57	7.24
2007	6.71	6.40	7.03
2014	6.95	6.48	7.43

There are no significant differences between years

Headline question: How is the ecological condition of section 42 (priority) habitats related to Glastir?

Blanket Bog

Background

Glastir options that are likely to affect the Blanket Bog habitat include 41a and 41b grazing management of open country with set maximum stocking rates, additional management options for re-wetting or stock reduction and the capital works for Grip blocking. Improving habitat condition is important for reducing the loss of Green House Gases; degraded blanket bog is more likely to be a source for carbon release into the atmosphere rather than a sink. Increasing the water levels and reducing the stocking rate are the main restoration objectives with a number of other activities that may be required e.g. re-seeding, gully stabilisation. In recent years there has been considerable activity in Wales to restore degraded blanket bog with a number of LIFE projects.

Methodology

As part of the field survey in 2013 and 2014 permanent vegetation plots were established. These include random plots (2002m) and 2m x 2m plots in Blanket Bog. Within the plots all higher plants were recorded to species level and a limited number of lower plants. Using the vegetation plot data a number of indicators have been calculated to report on habitat condition. The total number of species within a plot has been calculated. The number of Common Standard Monitoring indicator species was calculated by taking species identified in the guidance for the priority habitat (JNCC) and in discussions with the BSBI and calculating the number of them within a plot. Soil data from soil cores taken at the 200m plots has also been used to calculate an indicator for soil carbon within the plot. The land in Glastir in the entry or advanced level schemes was overlaid with the GMEP survey squares, whether or not the square was under Glastir management was used as a factor in the analysis. In future it will be possible to look at specific options spatially (allowing for suitable sample sizes) to assess whether a particular option is having an effect.

Results

The only significant result from comparing land under Glastir management with land outside of Glastir management is that there is a higher species richness in blanket Bog in a square subject to Glastir management.

This will reflect the baseline quality of the land entering the scheme rather than current Glastir management prescriptions as it takes such habitats some time to change (hydrology can change within a couple of years but vegetation and GHG emissions can take up to ten years to recover after restoration).

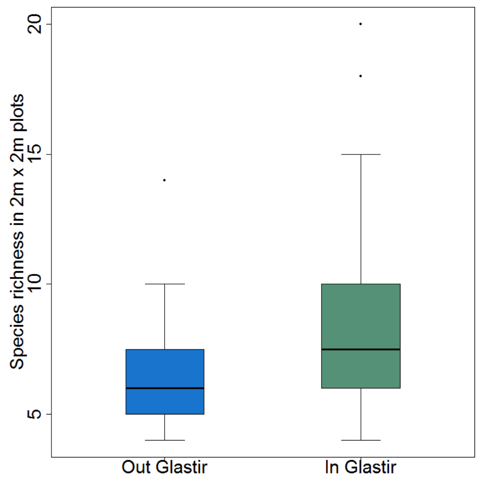


Figure 1: Species richness in 2m x 2m plots in Blanket Bog

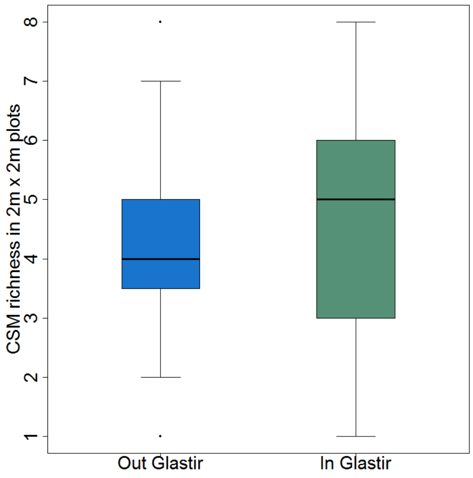


Figure 2: CSM richness in 2m x 2m plots in Blanket Bog

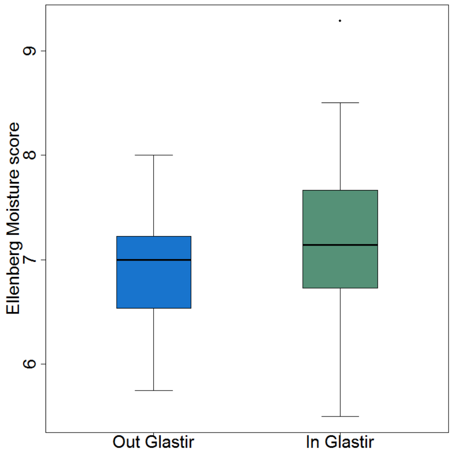


Figure 3: Ellenberg Moisture score in 2m x 2m plots in Blanket Bog

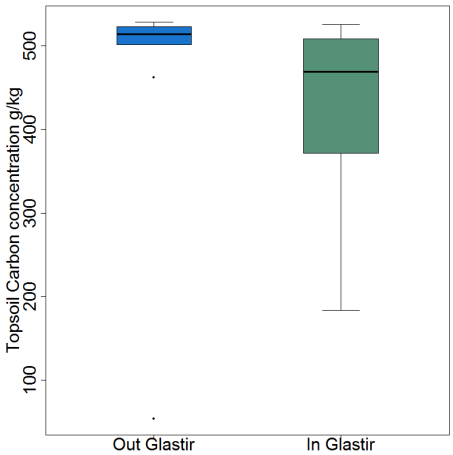


Figure 4: Topsoil Carbon concentration g/kg in Blanket Bog

Table 1: Species richness in 2m x 2m plots in Blanket Bog

Glastir	Estimated_Value	Lower_est.	Upper_est.
0	6.39	4.35	8.43
1	9.17	8.05	10.30

There is a significant difference between land in Glastir and land outside Glastir

Table 2: CSM richness in 2m x 2m plots in Blanket Bog

Glastir	Estimated_Value	Lower_est.	Upper_est.
0	4.05	3.16	4.95
1	4.84	4.31	5.37

There is no significant difference between land in Glastir and land outside Glastir

Table 3: Ellenberg Moisture score in 2m x 2m plots in Blanket Bog

Glastir	Estimated_Value	Lower_est.	Upper_est.
0	7.02	6.69	7.35
1	7.26	7.07	7.46

There is no significant difference between land in Glastir and land outside Glastir

Table 4: Topsoil Carbon concentration g/kg in Blanket Bog

Glastir	Estimated_Value	Lower_est.	Upper_est.
0	364.15	166.35	561.95
1	441.11	286.27	595.96

There is no significant difference between land in Glastir and land outside Glastir

What are the long term trends in the condition of priority (section 42) habitats? Purple Moor grass and Rush Pasture

Background

Purple moor grass and rush pastures occur on poorly drained, usually acidic soils in lowland areas of high rainfall. Purple moor grass *Molinia caerulea,* and rushes, especially sharp-flowered rush *Juncus acutiflorus*, are usually abundant. Acid indicators may be present but especially notable are uncommon assemblages of rich fen species such as *Juncus subnodulosus (*blunt flowered rush*), Carex pulicaris* (flea sedge), *Carex hostiana* (Tawny sedge*), Cirsium dissectum* (meadow thistle), *Epipactis palustris* (marsh helleborine)*, Gymnadenea conopsea (*fragrant orchid) and *Serratula tinctoria* (saw-wort).It is a reasonably common habitat type in Wales and composed 5% of the area of GMEP survey squares. It is classified as marshy grassland under Glastir (NVC M22-26) and subject to marshy grassland Glastir options. The condition of Purple Moor grass can be measured in a number of ways, Some indicators from GMEP include plant species richness, plant preference score for moisture

Methods

As part of the field survey in 2013 and 2014 permanent vegetation plots were established. These include random plots (200^2m) and 2m x 2m plots in Purple Moor grass rush pasture. Within the plots all higher plants were recorded to species level and a limited number of lower plants. Using the vegetation plot data a number of indicators have been calculated to report on habitat condition. The total number of species within a plot has been calculated. The number of Common Standard Monitoring indicator species was calculated by taking species identified in the guidance for the priority habitat (JNCC) and in discussions with the BSBI and identifying characteristic Purple Moor grass indicators. The number of characteristic (CSM) species within a plot was then calculated. Scores indicating plant preferences for moisture (Ellenberg wetness index) have also been calculated, each plant has an individual wetness score and an average is then taken for a plot, higher scores indicate wetter conditions. Data from Countryside Survey has been used for the long term trend but Purple Moor grass rush pasture was surveyed for the first time in 2007 so the trend only goes back to there.

Results

Purple Moor grass Rush pasture was recorded for the first time as a distinct habitat type in 2007 Countryside Survey so the trend only goes from 2007.

There were no significant differences in the number of characteristic plant species (CSM), Total plant species richness or plant moisture (Ellenberg) scores in 2m x 2m plots between 2007 and the GMEP 2013/2014 sample. This suggests that there has been no significant change in the condition of Purple Moor grass rush pasture.

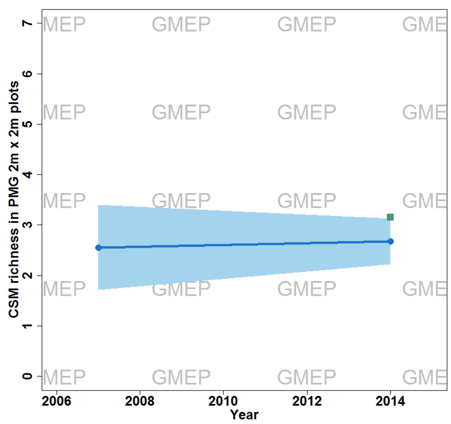


Figure 1: The trend in the characteristic species (CSM) richness in a 2m x 2m plot

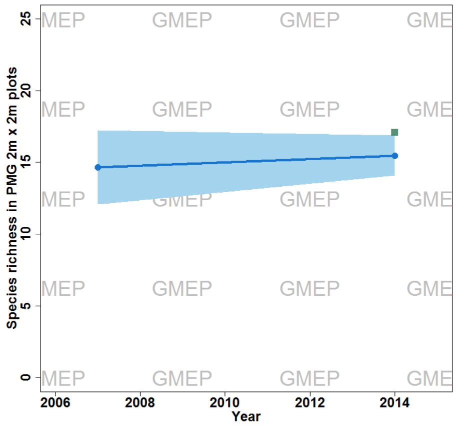


Figure 2: The trend in the Total plant species richness in a 2m x 2m plot

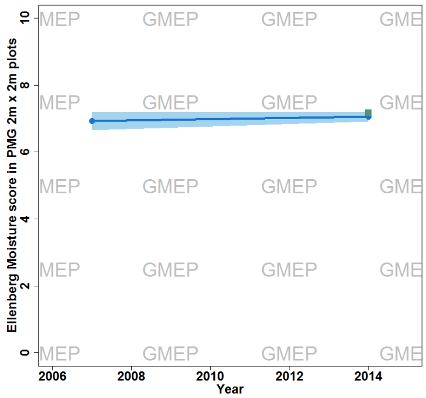


Figure 3: The trend in Ellenberg moisture score in a 2m x 2m plot

Table 1 The trend in the characteristic (CSM)plant species richness in a 2m x 2m plot

Year	Estimated_Value	Lower_est.	Upper_est.
2007	2.56	1.71	3.40
2014	2.68	2.22	3.13

There is no significant difference in characteristic (CSM) species richness between 2007 and 2013/14

Table 2: The trend in total plant species richness in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
2007	14.67	12.07	17.26
2014	15.48	14.09	16.88

There is no significant difference in Total species richness between 2007 and 2013/14

Table 3: The trend in mean Ellenberg Moisture score in 2m x 2m plots

Year	Estimated_Value	Lower_est.	Upper_est.
2007	6.93	6.73	7.12
2014	7.07	6.93	7.21

There is no significant difference in plant moisture score (Ellenberg) between 2007 and 2013/14.

Appendix 5.12: What are the long term trends in Habitat diversity?

Background

Habitat diversity can be a good thing in that a mixture of habitats provides variety in abiotic conditions, food and shelter and is preferable to a species-poor monoculture. High habitat diversity should provide resilience from changing environmental conditions (e.g. climate change) enabling species to move between habitats when conditions change. However, high habitat diversity can also be a sign of increasing fragmentation and it is important that larger continuous areas of habitat are also maintained for example, in unenclosed upland environments. Habitat diversity and connectivity (reported elsewhere) can both contribute to the creation of ecological networks which have an important role to play in the conservation of habitats and species in an increasingly fragmented landscape.

Methods

Habitat diversity and the mean area of a habitat patch within a 1km square have been calculated from field survey data. All Habitats are mapped within a 1km square to Broad and Priority habitat classification by surveyors in the field using a computer with bespoke GIS technology. This classification has been applied continuously from 1984 to 2014. The Shannon diversity index (H´) following the formula $-\Sigma\, p_i \ln p_i$, was used to calculate habitat diversity where p_i, is the proportion of habitat $_i$. Habitats were substituted for species and 1km squares for quadrats. Urban areas were excluded and all Priority Habitat types were included as separate habitats. The mean patch size was calculated from the area data as a mean per 1km square.

Results

There has been no significant change in habitat diversity between 1984 and 2014.
Although Figure 2 does suggest an increasing trend in mean patch size the There has been no significant change in mean patch size between 1984 and 2014.

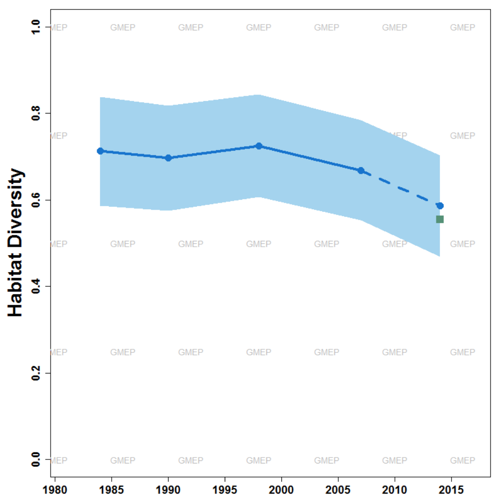


Figure 1: Trends in habitat diversity (Shannon diversity index) between 1984 and 2014

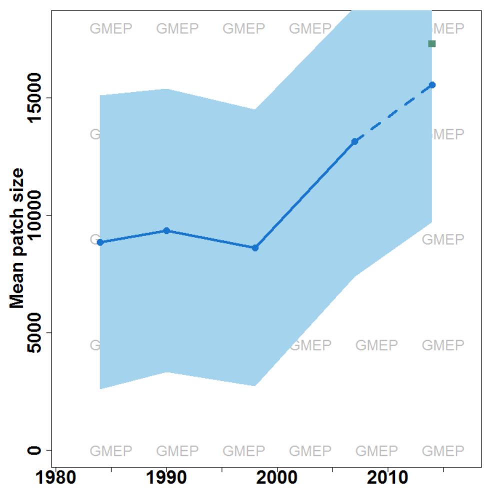


Figure 2: Trends in mean habitat patch size between 1984 and 2014

Table 1: Mean Habitat Diversity over Time

Year	Estimated_Value	Lower_est.	Upper_est.
1984	0.71	0.59	0.84
1990	0.70	0.58	0.82
1998	0.73	0.61	0.84
2007	0.67	0.55	0.78
2013/14 GMEP	0.59	0.47	0.70

There are no significant differences between years

Table 2: Changes in mean patch size over time

Year	Estimated_Value	Lower_est.	Upper_est.
1984	8860.33	2609.50	15111.17
1990	9364.52	3339.38	15389.67
1998	8619.06	2725.65	14512.47
2007	13142.26	7398.74	18885.77
2013/14 GMEP	15554.23	9715.08	21393.38

There are no significant differences between years

Does habitat diversity vary according to whether land is in Glastir?
Within Glastir high habitat diversity as such is not an objective of the scheme but maintaining areas of habitat land in good condition is important. It is a useful measure to assess whether land in and out of Glastir consist of higher habitat diversity at this stage of the scheme.

Methods
Habitat diversity was calculated as described above. The land in Glastir in the entry or advanced level schemes was overlaid with the GMEP survey squares, whether or not the square was under Glastir management was used as a factor in the analysis. In future it will be possible to look at specific options spatially (allowing for suitable sample sizes) to assess whether a particular option is having an effect.

Results
Habitat Diversity is higher in 1km squares that are subject to Glastir management.

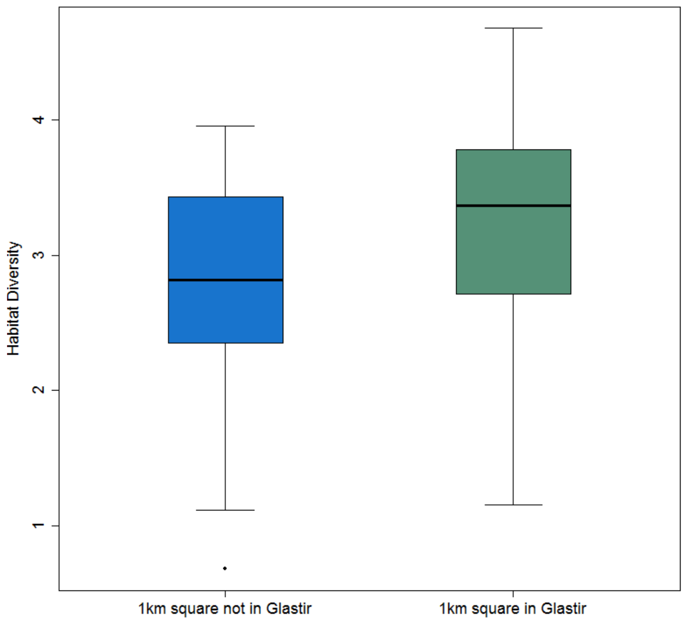


Figure 3: Mean Habitat diversity per 1km square where land is managed under Glastir and is not in Glastir.

Table 1: Mean Habitat diversity per 1km2 in a 1km square where land is in Glastir and land is not in Glastir

Glastir	Estimated_Value	Lower_est.	Upper_est.
0	2.815193	2.549823	3.080562
1	3.185736	3.042068	3.329405

There is a significant difference between squares where the land owner is in Glastir and squares where the land owner is not in Glastir

Appendix 5.13 How many priority habitats are sampled in the GMEP field survey and how many Priority habitats coincide with Glastir agreement maps by the end of year 2?

Background

There are a number of habitats of principle importance to conservation in Wales which are known as 'Priority' habitats or section 42 habitats. The production of a section 42 list is a requirement of the Natural Environment and Rural Communities Act 2006, and is used to guide and prioritise future conservation action in Wales. Some of these priority habitats are specifically mentioned as targets in Glastir e.g. Lowland heathland, wetland and there are options in the scheme designed to optimise management to ensure that they are in good condition. Many of these habitats are important to priority and section 42 species and management and creation options in Glastir are designed to benefit them. In GMEP, priority and broad habitats are mapped in every 1km square, this includes large areas of habitat e.g. blanket bog but also linear features such as streamsides, hedgerows and belts of trees. This question addresses the number and type of habitats surveyed in GMEP but also goes wider to look at the habitats covered by Glastir uptake to date.

Methodology

In the GMEP field survey the habitats and features of every 1km square are mapped using a bespoke GIS software system on field computers. As well as classifying each habitat type using a vegetation key many detailed attributes are recorded such as the height of the vegetation, the species composition, the management and use and the condition. This gives us a detailed complex database that can be queried to determine how habitats and features vary spatially and how they are changing and how they are influenced by management actions. It is also valuable information to contribute to studies of priority species.

Results

Figure 1 shows the % of the GMEP square area attributed to different habitat types.
The most commonly surveyed habitats are the Broad habitats improved, neutral and acid grasslands and coniferous and Broadleaved woodland. These make up a large proportion of the Welsh countryside. The most frequently surveyed priority habitats include Purple Moor Grass rush pasture, upland heath, Blanket Bog and some of the woodland priority habitats wet woodland and Lowland mixed deciduous. Most of the priority habitat types are recorded in the GMEP survey but some make up a very low percentage of the survey. Upland habitats are better represented in the targeted squares which is to be expected as these were chosen to reflect the Welsh Government priorities in the first two years of Carbon and water.
Figure 2 shows the percentage of the total area of different habitats in Wales that are currently under a Glastir scheme. Acid, calcareous and marshy grassland (includes Purple Moor grass Rush pasture) are well covered by Glastir agreements as are bogs, mires and heathlands. Woodland habitats are less well covered with only 22.7 % of semi-natural broadleaved woodland being under Glastir agreement.

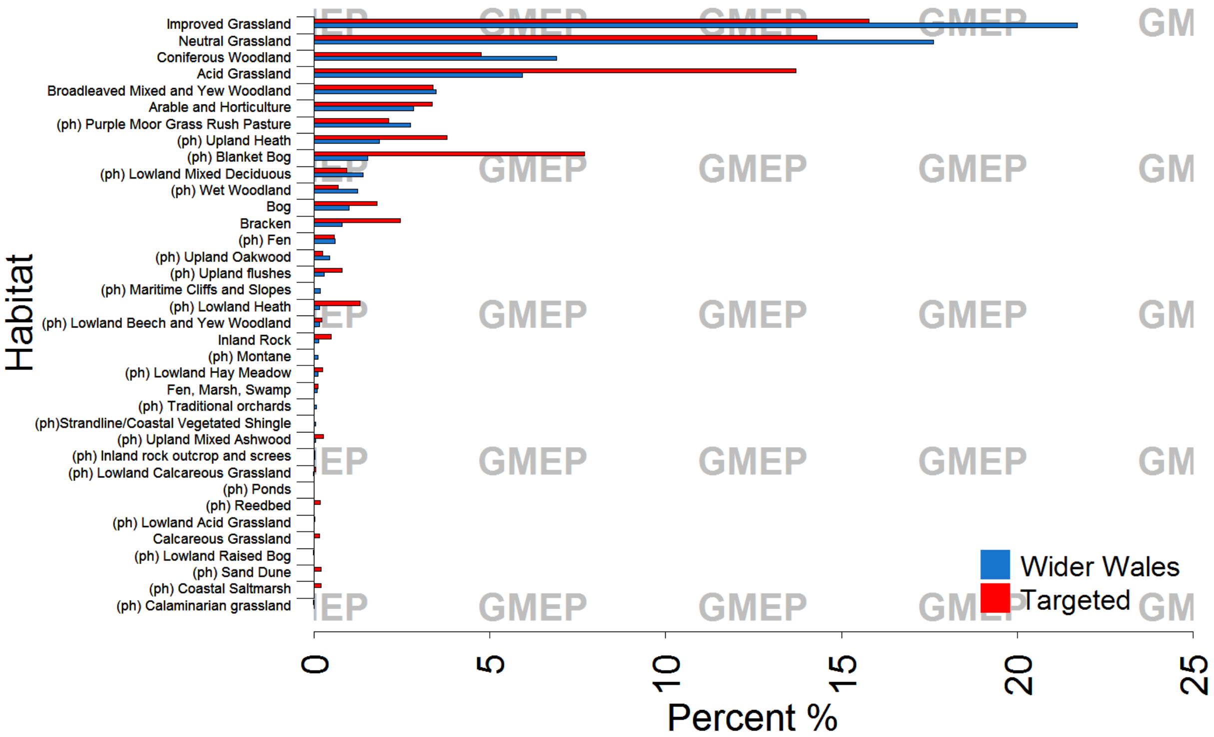


Figure 1: Percentage of habitats surveyed in the GMEP field survey, the broad habitat figures do not include those areas also identified as priority habitat.

Table 1: Data from GMEP field survey showing coverage of different Broad and Priority habitats within the field survey

Habitat	%WW	%TG
Improved Grassland	21.7	15.77
Neutral Grassland	17.61	14.29
Coniferous Woodland	6.91	4.76
Acid Grassland	5.93	13.7
Broadleaved Mixed and Yew Woodland	3.47	3.38
Arable and Horticulture	2.83	3.37
(ph) Purple Moor Grass Rush Pasture	2.74	2.13
(ph) Upland Heath	1.86	3.79
(ph) Blanket Bog	1.53	7.7
(ph) Lowland Mixed Deciduous	1.4	0.93
(ph) Wet Woodland	1.25	0.7
Bog	1.01	1.79
Bracken	0.81	2.47
(ph) Fen	0.61	0.58
(ph) Upland Oakwood	0.45	0.25
(ph) Upland flushes	0.3	0.81
Standing Open Waters and Canals	0.2	1.32
(ph) Maritime Cliffs and Slopes	0.19	0.01
(ph) Lowland Heath	0.16	1.31
(ph) Lowland Beech and Yew Woodland	0.16	0.23

Inland Rock	0.15	0.5
Rivers and Streams	0.14	0.19
(ph) Montane	0.13	0
(ph) Lowland Hay Meadow	0.12	0.26
Fen, Marsh, Swamp	0.1	0.12
(ph) Traditional orchards	0.07	0.01
(ph)Strandline/Coastal Vegetated Shingle	0.05	0.01
(ph) Upland Mixed Ashwood	0.05	0.27
(ph) Inland rock outcrop and screes	0.03	0.03
(ph) Lowland Calcareous Grassland	0.02	0.05
(ph) Ponds	0.01	0.01
(ph) Reedbed	0	0.19
(ph) Lowland Acid Grassland	0	0.04
Calcareous Grassland	0	0.16
ph) Lowland Raised Bog	0	0.02
ph) Sand Dune	0	0.2
(ph) Coastal Saltmarsh	0	0.22
(ph) Calaminarian grassland	0	0.02

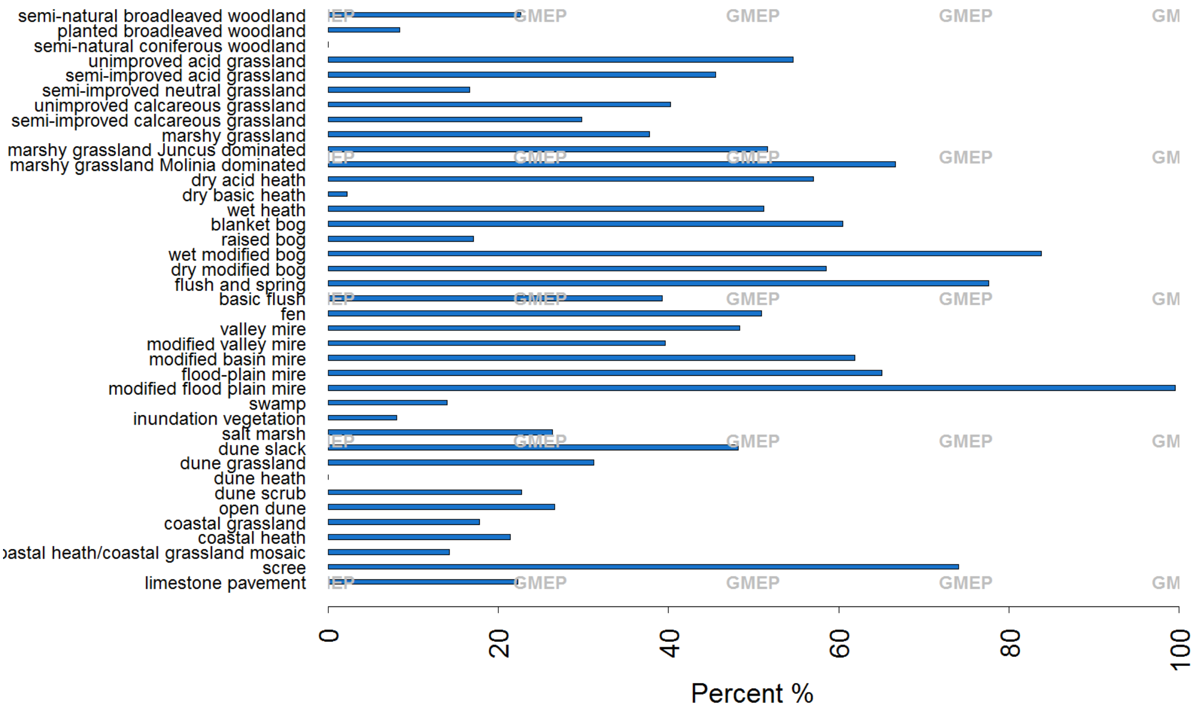


Figure 2: Percentage of total area of each habitat in Wales covered by a Glastir scheme (includes all schemes, entry, advanced, Woodland element, commons, GEG) and uses NRW Phase 1 survey data to represent habitat coverage

Table 2: Data from NRW Phase 1 Habitat map overlaying land under Glastir scheme to determine approximate percentage of different habitat types under Glastir management across the whole of Wales.

	Code	Habitat	Glastir ENTRY	Glastir ADVANCED	Glastir Woodland Management	Glastir COMMONS	Glastir GEG	Glastir Total
Woodland and scrub	A.1.1.1	semi-natural broadleaved woodland	21.11	1.98	1.44	0.18	0.88	22.70
	A.1.1.2	planted broadleaved woodland	7.11	0.63	1.17	0.07	0.27	8.42
	A.1.2.1	semi-natural coniferous woodland	0.00	0.00	0.00	0.00	0.00	0.00
	A.1.3.1	semi-natural mixed woodland	6.03	0.72	1.67	0.00	0.00	6.03
	A.1.3.2	planted mixed woodland	8.77	0.61	3.79	0.02	1.28	12.04
Grassland and marsh	B.1.1	unimproved acid grassland	40.62	9.70	0.03	13.97	0.55	54.67
	B.1.2	semi-improved acid grassland	43.20	7.14	0.06	1.93	1.39	45.53
	B.2.2	semi-improved neutral grassland	15.94	1.65	0.08	0.49	0.31	16.62
	B.3.1	unimproved calcareous grassland	15.98	1.70	0.00	24.25	0.02	40.23
	B.3.2	semi-improved calcareous grassland	7.88	1.02	0.00	21.98	0.41	29.85
	B.5	marshy grassland	35.64	7.14	0.06	1.91	0.88	37.77
	B.5.1	marshy grassland Juncus dominated	30.56	4.71	0.00	21.11	0.18	51.67
	B.5.2	marshy grassland Molinia dominated	41.70	8.35	0.00	24.97	0.11	66.69
Heathland	D.1.1	dry acid heath	33.23	7.64	0.09	23.67	0.28	57.02
	D.1.2	dry basic heath	1.35	0.00	0.00	0.89	0.00	2.25
	D.2	wet heath	35.24	11.22	0.07	15.62	0.56	51.15
	D.3	lichen/bryophyte heath	54.28	0.00	0.00	9.22	0.00	63.49
	D.5	dry heath/acid grassland mosaic	32.85	6.67	0.09	24.77	0.27	57.87
	D.6	wet heath/acid grassland mosaic	54.10	23.96	0.00	4.99	0.64	59.55
	D.7	basic dry heath/calcareous grassland mosaic	0.55	0.00	0.00	0.00	0.00	0.55
Mire	E.1.6.1	blanket bog	50.45	19.57	0.00	10.03	0.76	60.49
	E.1.6.2	raised bog	14.29	7.40	0.00	2.82	0.00	17.12
	E.1.7	wet modified bog	65.45	44.11	0.01	18.35	0.37	83.82
	E.1.8	dry modified bog	22.89	4.32	0.00	35.69	0.41	58.54
	E.2	flush and spring	70.39	61.67	0.00	7.26	7.06	77.65
	E.2.1	acid/neutral flush	38.75	9.92	0.01	16.11	0.31	54.90
	E.2.2	basic flush	19.79	16.09	0.00	19.48	0.04	39.27
	E.3	fen	46.41	11.01	0.01	4.33	0.51	50.93
	E.3.1	valley mire	26.85	8.99	0.00	21.05	0.01	48.33
	E.3.1.1	modified valley mire	37.94	7.14	0.05	1.59	0.00	39.59

	E.3.2	basin mire	38.92	14.62	0.21	12.55	5.33	52.01
	E.3.2.1	modified basin mire	49.85	48.74	0.00	12.00	0.00	61.85
	E.3.3	flood-plain mire	65.09	57.71	0.00	0.00	0.00	65.09
	E.3.3.1	modified flood plain mire	99.49	99.49	0.00	0.00	0.00	99.49
Swamp, marginal and inundation	F.1	swamp	12.07	3.64	0.73	1.26	0.35	14.00
	F.2.2	inundation vegetation	5.83	0.17	1.06	1.18	0.00	8.07
Coastland	H.2.6	salt marsh	26.29	8.90	0.00	0.09	0.00	26.38
	H.6.4	dune slack	44.13	13.17	0.00	4.07	0.00	48.20
	H.6.5	dune grassland	25.95	0.42	0.00	5.29	0.00	31.25
	H.6.6	dune heath	0.00	0.00	0.00	0.00	0.00	0.00
	H.6.7	dune scrub	22.64	10.29	0.00	0.09	0.00	22.73
	H.6.8	open dune	22.78	1.74	0.00	3.86	0.00	26.64
	H.8.1	hard cliff	8.61	0.47	0.00	0.38	0.00	8.99
	H.8.2	soft cliff	9.15	0.01	0.00	0.00	0.00	9.15
	H.8.4	coastal grassland	17.06	4.70	0.01	0.74	0.77	17.84
	H.8.5	coastal heath	21.45	4.82	0.00	0.00	0.00	21.45
	H.8.6	coastal heath/coastal grassland mosaic	14.26	0.82	0.00	0.00	0.00	14.26
Rock	I.1.2	scree	64.73	21.28	0.00	9.30	0.00	74.03
	I.1.2.1	acid/neutral scree	43.25	4.98	0.00	5.25	0.06	48.72
	I.1.2.2	basic scree	3.52	0.00	0.00	0.00	0.00	3.52
	I.1.3	limestone pavement	22.32	6.22	0.00	0.02	0.00	22.34

Appendix 5.14: Extending beyond field squares: Net Primary Productivity (NPP) mapping

Introduction
Traditional land cover mapping focusses on determining a single land cover type for a particular pixel or parcel of land. However, this rarely captures the complexity of the landscape, so methods have been developed that aim to capture the heterogeneity by identifying a number of classes for each pixel or parcel using fuzzy classification methods. This enables a more sophisticated description of the between-class variation in the landscape, but fails to capture the within-class variation of the different classes. Users are increasingly demanding a more nuanced picture of the landscape to enable remote sensing to routinely be used to monitor change in land cover/habitat, and changes in condition. To meet these new user requirements requires new methods and products to be developed to enhance traditional land cover mapping products.

The Normalised Difference Vegetation Index (NDVI), derived from remotely sensed imagery, can be used as an indicator for vegetation productivity. The exact form of the relationship between NDVI and productivity depends on several factors including the satellite sensor and the habitat type; therefore, *in situ* data is required to calibrate the relationship. The advantage of continuous biophysical products is that they: (i) Capture sub-polygon and within class variability, so gradients in grassland productivity across a specific field will be mapped, as will the wider variations across a region, or across different regions; (ii) Are a key requirement of condition monitoring and early detection of land cover change; (iii) Enable more sophisticated-modelling – by quantifying differences in different pixels/parcels of the same land-cover type. For example, by identifying both areas of grassland (from the categorical data) and areas of higher and lower productivity grassland (from the continuous data).
The aim here was to combine detailed field survey data and broad scale remote sensing data to produce a map of Net Primary Productivity (NPP) for the whole of Wales.

Method
The overall approach was to use ANPP values derived from GMEP field survey data in combination with remotely sensed NDVI imagery to derive a relationship between ANPP and NDVI, which could then be used to extrapolate beyond the survey squares and produce a map of NPP for Wales.
In situ Specific Leaf Area (SLA) measurements from 707 x-plots within 150 1 km squares across Wales, surveyed over 2013 and 2014, were used to estimate Annual NPP (ANPP) values based on the method described in Stevens *et al*. (In prep.). Landsat 8 imagery for Wales was downloaded for the years 2013 and 2014. The raw digital numbers were calibrated to TOA reflectance and clouds and cloud shadows were masked out of the imagery. The red and NIR bands were used to produce NDVI images, NDVI = (NIR-red)/(NIR+red), and NDVI values for each x-plot were extracted from the imagery using the plot coordinates. Cloud free Landsat 5 TM surface reflectance NDVI imagery from 2011 was also used to illustrate what is possible under cloud free conditions.
Least squares linear regression was used to determine the strength and form of the image-specific relationship between ANPP and NDVI. This was initially done for grassland habitats, as these were expected to give the strongest relationships, and then for all habitat types. The derived relationships were then applied to the NDVI imagery to produce maps of ANPP for all grasslands across Wales. Land Cover Map 2007 was used to produce a mask of all non-grassland habitats in order to exclude these areas from the resulting map.

Results
Relationship between ANPP and NDVI for grassland habitats
Results showed that the relationship between ANPP and NDVI for grassland habitats had a seasonal dependence. The strongest relationship was seen in the spring and autumn (e.g. Figure 1), while in the summer and winter months, the correlation was very weak (e.g. Figure 2). Variation in the slope

and the R^2 value for the relationship between ANPP and NDVI is shown in Figure 3. The strong correlations observed for spring images is likely to be due to differences in the ‘greening up’ times of the different plots, i.e. the more productive grasslands will green up earlier in the year than less productive ones. Similarly, in the autumn, the highly productive grasslands will continue to grow later into the season than the low productivity grasslands. In the summer and winter images all grasslands have reached a similar level of ‘greenness’ and hence, there is very little variation in NDVI across the productivity gradient.

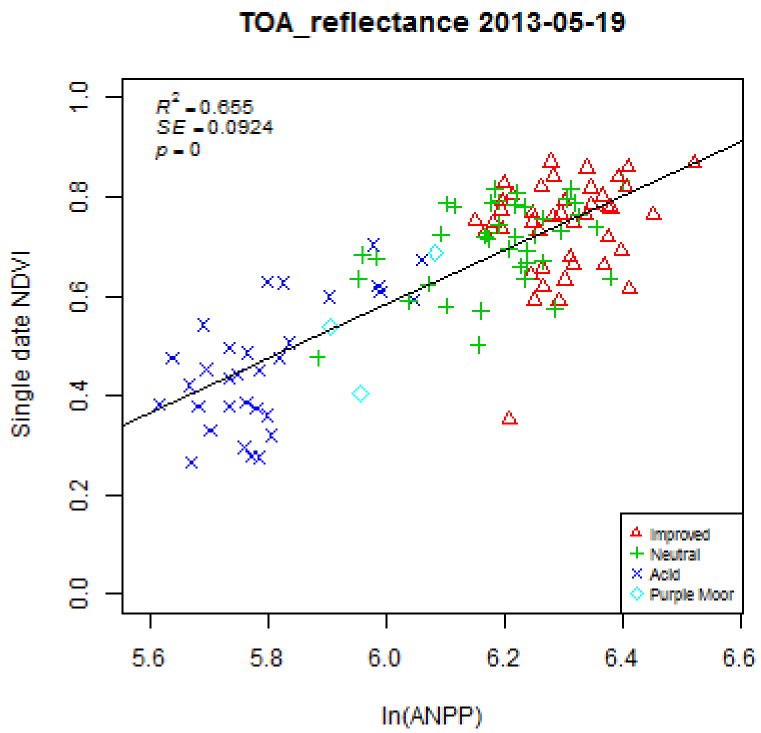


Figure 1. Scatter plot showing the relationship between NDVI and ln(ANPP) for grassland habitat based on a spring image, 2013-05-19.

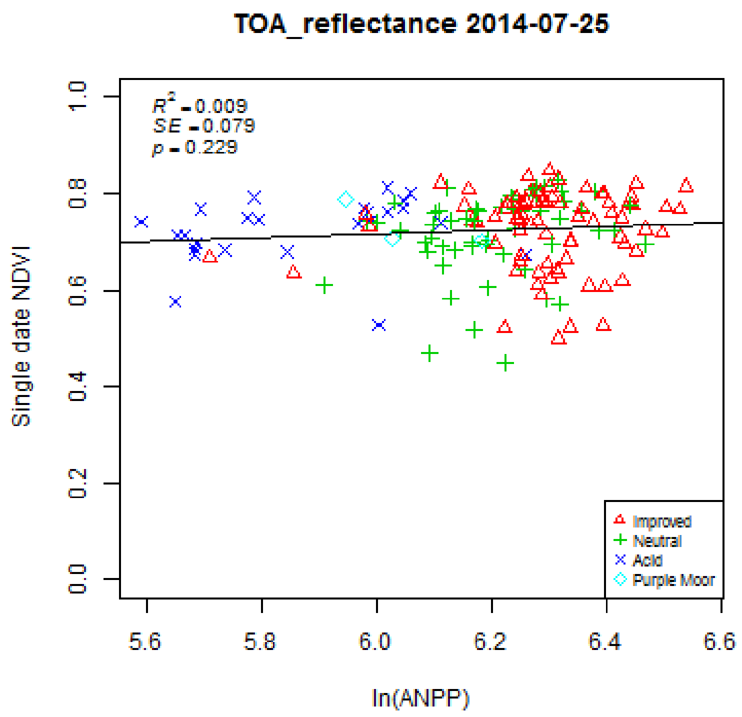


Figure 2. Scatter plot showing the relationship between NDVI and ln(ANPP) for grassland habitats based on a summer image, 2014-07-25.

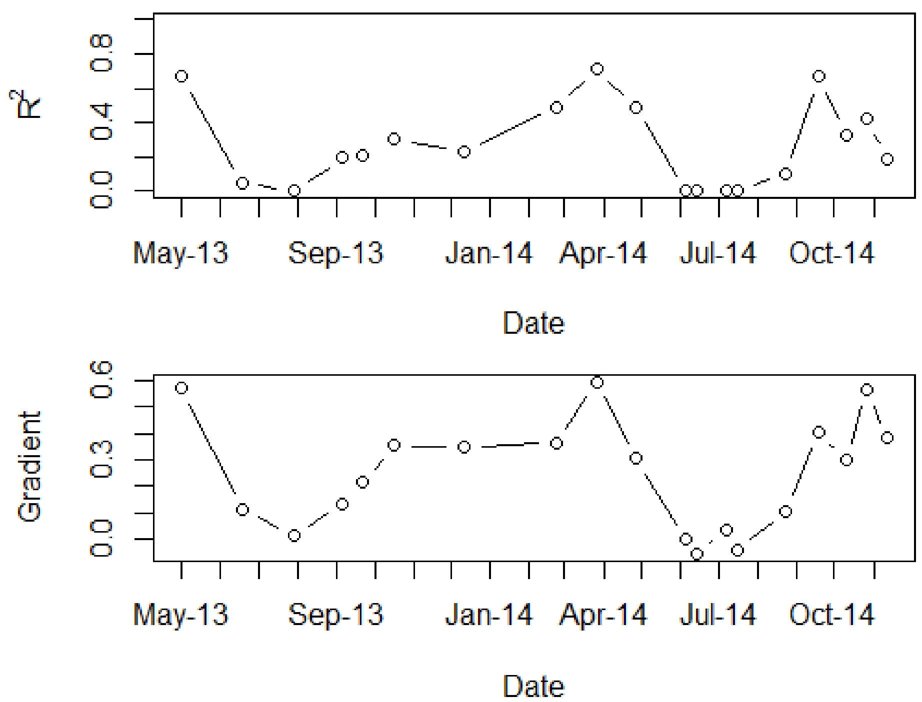


Figure 3. Time series of gradient and R^2 values for the relationship between ANPP and NDVI for grassland habitats.

Relationship between ANPP and NDVI for all habitat types

When all habitat types were considered, a similar seasonal dependence in the relationship between ANPP and NDVI was observed, with the strongest relationship occurring in the spring (Figure 4) and the weakest in summer and winter (Figure 5). The R^2 values were lower when all habitat types were included as there was more scatter in the relationship. Arable, dwarf shrub heath and coniferous habitats did not fit in well with the relationship shown by the other habitat types. In some scatter plots, broadleaved woodland appeared to be anomalous. Arable was expected to give anomalous results since the observed NDVI value is very sensitive to the timing of the image relative to time of planting and harvest. Hence, the methodology presented here is not suitable for estimating the productivity of arable land. For dwarf shrub heath, coniferous and deciduous the deviation from the trend observed for the other habitat types is likely to be due to problems with the trait based model used to estimate the *in situ* ANPP values. These issues are expected to be improved in a future version of the model which is currently being developed.

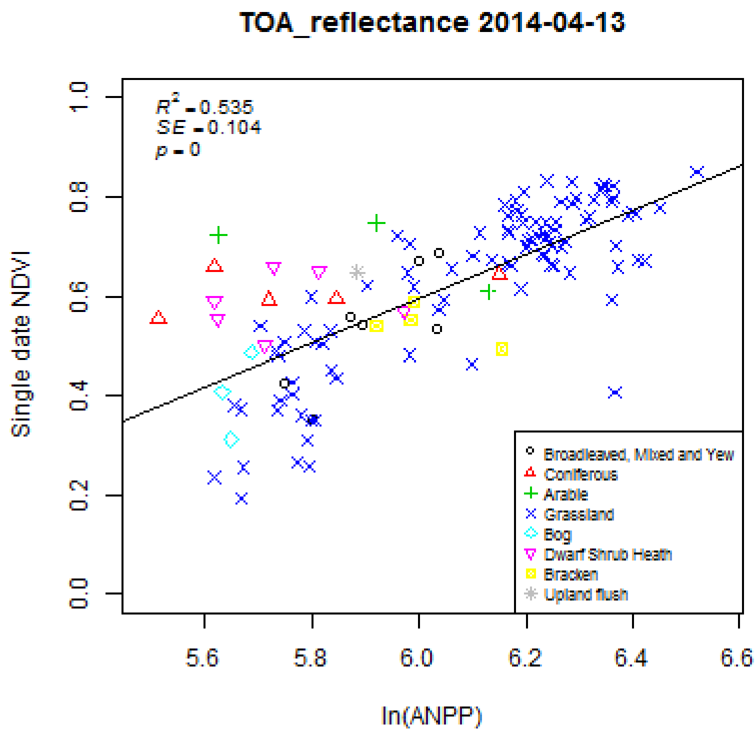


Figure 4. Scatter plot of ln(ANPP) versus NDVI for a spring image, 2014-04-13, for all habitat types

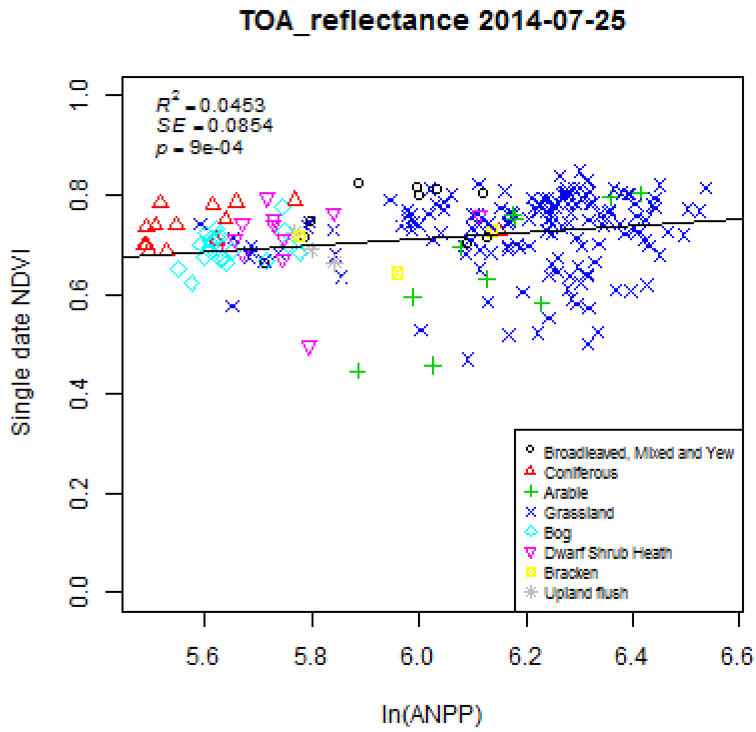


Figure 5. Scatter plot of ln(ANPP) versus NDVI for a summer image, 2014-07-25, for all habitat types.

ANPP maps

The Landsat 8 NDVI image captured on 2014-04-13 gave the highest correlation with *in situ* ANPP measurements (R^2 = 0.714; Figure 6). The relationship between NDVI and ln(ANPP), derived using least squares linear regression, for this image was:

$$\ln(ANPP) = 1.21 \times NDVI_{L8\ TOA} + 5.35$$

where $NDVI_{L8\ TOA}$ is the NDVI value calculated from Landsat 8 top-of-atmosphere reflectance. Figure 7 shows the ANPP map which was produced by applying this equation to the NDVI, after first masking out cloud and non-grassland habitats. The map illustrates the problem of cloud cover, as large portions of the image were obscured by cloud.

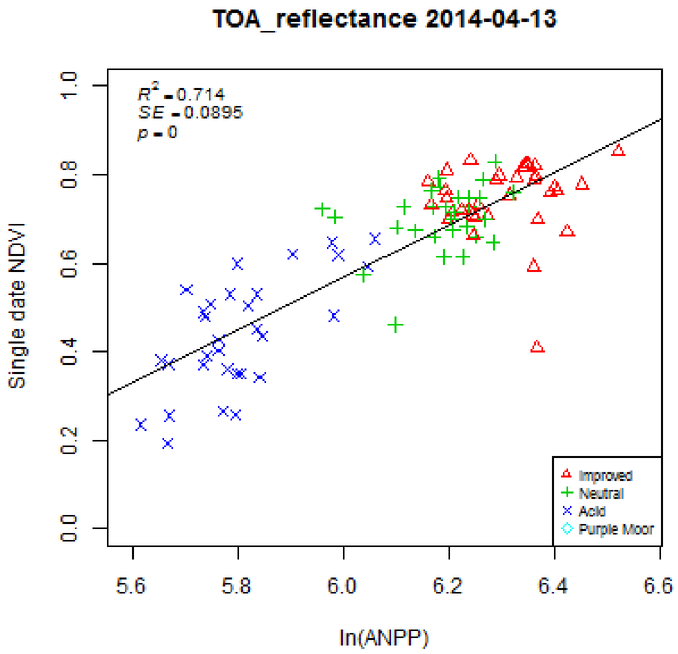


Figure 6. Scatter plot showing the relationship between NDVI and ln(ANPP) for grassland habitat based on a Landsat 8 image captured on 2014-04-13.

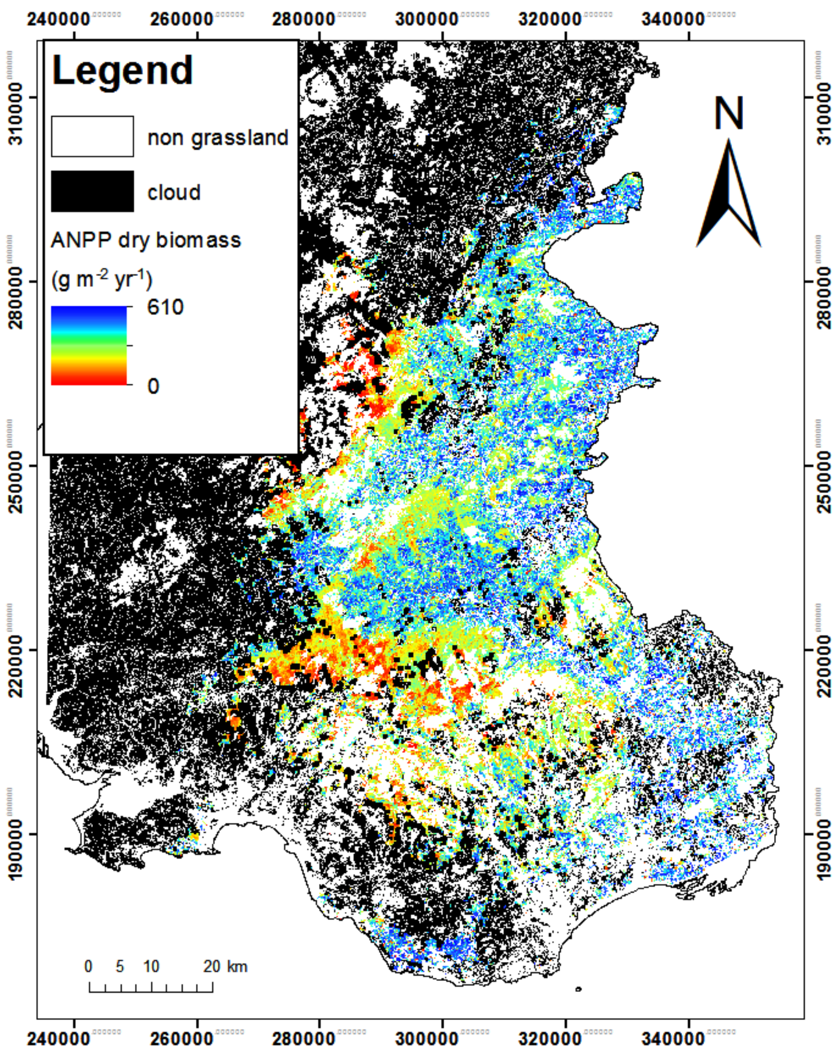


Figure 7. Map of ANPP for south-east Wales produced using a Landsat 8 image captured on 2014-04-13.

To illustrate what is possible with good cloud free imagery, two cloud free Landsat 5 TM images from 2011-04-28 were downloaded. The two images covered almost the whole of Wales, apart from a small strip of south east Wales. Figure 8 shows the scatter plot produced using these two Landsat scenes. The R^2 value for the relationship is lower than for the Landsat 8 imagery, and there is more scatter in the relationship. This could be due to the temporal separation of the satellite image (2011) and the *in situ* data (2013 and 2014), which could have led to phenological differences or changes land cover type some plots. Alternatively the weaker relationship could be due to limitations of the Landsat TM 5 sensor. Despite the weaker relationship, the correlation was still significant and therefore it was reasonable to use the model to predict ANPP value beyond the survey squares. The relationship between ln(ANPP) and NDVI for these images, derived using least squares linear regression, had the form:

$$\ln(ANPP) = 0.888 \times NDVI_{LT5} + 5.50$$

where $NDVI_{LT5}$ is the NDVI value derived from Landsat 5 TM surface reflectance. Figure 9 shows the ANPP map produced by applying this equation to two Landsat 5 TM scenes.

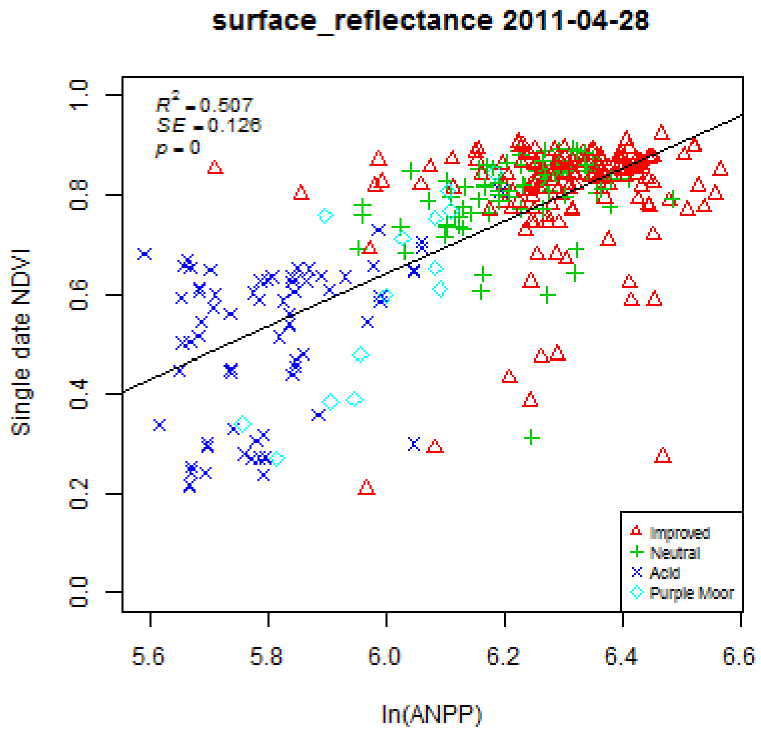


Figure 8. Scatter plot showing the relationship between NDVI and ln(ANPP) for grassland habitat based on a Landsat 5 TM image captured on 2011-04-28.

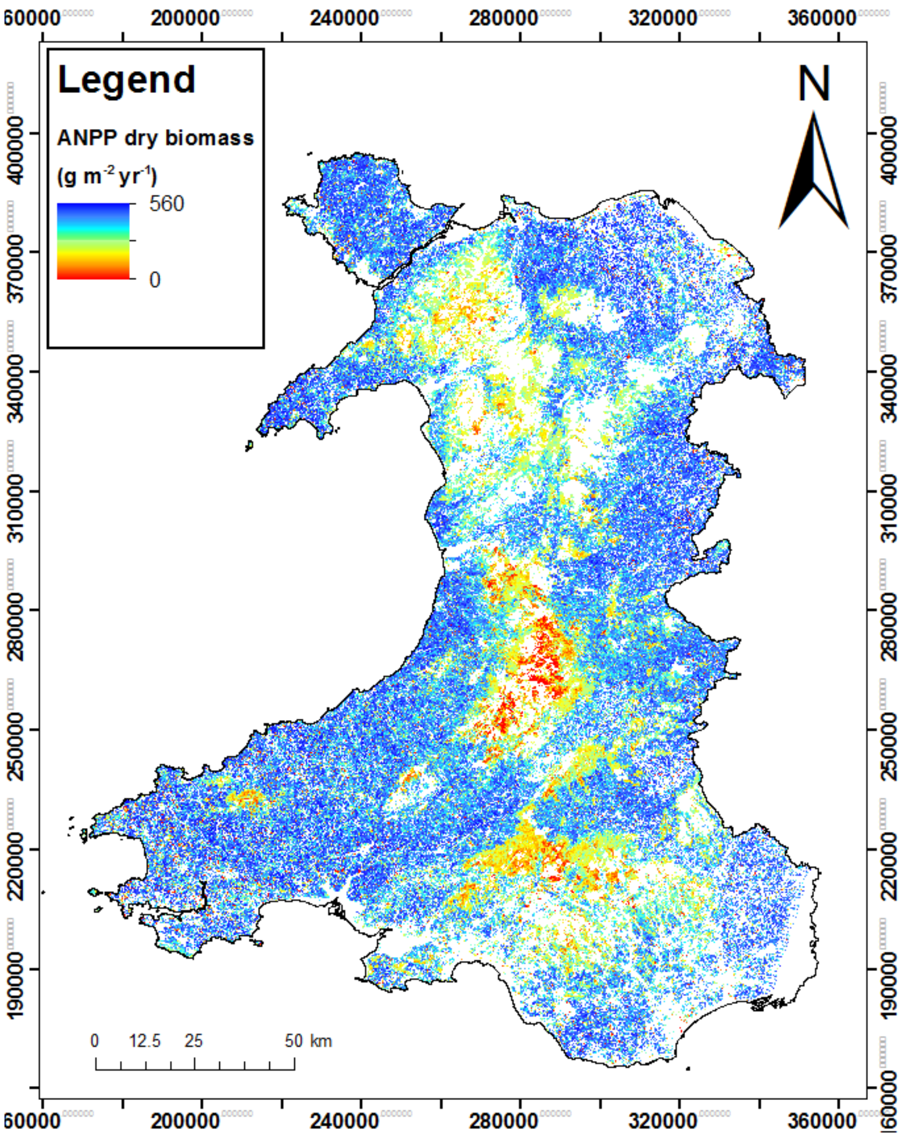


Figure 9. ANPP map for Wales produced using Landsat 5 TM imagery from 2011

Conclusions

A method has been demonstrated for extrapolating variables calculated from field measurements beyond the survey squares to produce maps of biophysical parameters at a national scale. In this example, maps of vegetation productivity were produced, but the method could also be applied to other variables, e.g. moisture content. It provides an alternative to traditional land cover mapping which divides the landscape up into discrete habitat types.

The results have shown the potential for using satellite data to extrapolate ANPP values spatially beyond the GMEP x-plots to produce ANPP maps for Wales. The correlations observed between the NDVI imagery and the ANPP values were reasonably strong, particularly considering that the *in situ* data were not designed specifically for validation of remotely sensed data. The plots are located randomly within each habitat patch so some plots may be at the edge of a land parcel and influenced by neighbouring land use or field margins/boundaries (for arable land plots are always located near the edge of the land parcel). The relationships derived are image-specific and hence, must be calibrated for each image using available *in situ* data. Furthermore, the method is dependent on cloud free imagery acquired in the spring or autumn, in order to give a relationship which is strong enough to justify extrapolating outside the survey squares and producing a product with a reasonable level of accuracy.

This method could potentially be used for monitoring changes in vegetation productivity over time. To do this would require obtaining sufficient cloud free imagery in the spring or autumn to produce a map of the whole of Wales. Currently, the availability of suitable cloud free imagery is limited; however, with the launch of the planned Sentinel-2 satellite, suitable optical imagery will become much more frequently collected, thereby increasing the probability that cloud free imagery will be acquired. Hence, it is conceivable that national scale vegetation productivity maps could be produced and updated every few years.

References

Stevens, C.J., T. Ceulemans, J.G. Hodgson, S. Jarvis, J.P. Grime & S.M. Smart. (In prep.). 'Changes in indicators of natural capital and ecosystem services across temperate grasslands; vegetation change in grasslands of the Sheffield region between 1965 and 2012/3'.

BARBASTELLE BAT

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Trees in unmanaged deciduous woodland (ancient or semi-natural) are favoured as roost trees, particularly dead or mature trees with splits, cracks and lose bark (Russo et al. 2004; Greenaway, 2001). As such this species is reliant on woodland managers to retain old or damaged trees necessary for roosting (Schofield & Fitzsimmons, 2004). The loose bark of dead oak trees is particularly used by both sexes of barbastelle bat for roosting (Greenaway, 2005). A study by Howorth (2009) found that woodland which has potential to be used by barbastelle was principally comprised of oak. Furthermore, a dense understorey/well developed shrub layer will aid humidity around roost trees and lower wind speeds; this is especially important for nursery roosts, as well as helping to maintain insect abundance and availability (Greenaway, 2004). Scrub and woodland understorey are the larval food of many small moths (Greenaway 2005); a rich shrub layer could be important in providing prey diversity (Sierro, 1999). A study in Italy showed barbastelles had a preference for oaks with a large circumference. This was thought to indicate the preference for old woodland with high diversity (Sierro, 1999). Barbastelles are specialist moth predators. The retention of woodland edges is beneficial as this enhances moth abundance and diversity (Zeale et al. 2012).	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing woodland • Stock excluded from woodland • Area of existing woodland • New area of scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • <u>% cover of shrub in deciduous woodland</u> • <u>% cover of oak in deciduous woodland</u> • <u>Moth numbers (woodland)</u>	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping Linears and Fence condition Habitat mapping; X & Y plot Habitat mapping; X & Y plot Invertebrate surveys?

Barbastelles benefit from rich hedges and have been seen frequently hunting along these features as they support high densities of moths (Zeale et al. 2012). Tree lines close to woodland roost sites provide connectivity and cover beyond woodland borders. This cover is particularly needed at dusk when leaving woodland roosting sites to forage (Zeale et al. 2012). As such, the larger hedges are left to grow, the more shade is provided and the better the flight line cover is for movement to foraging sites (Greenaway 2004, 2005). In particular, continuous double hedge lines are ideal (i.e. second line of trees are shrubs planted parallel to existing hedgerow) where woodland connectivity breaks down into hedgerows (Greenaway, 2004).	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; ≥ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots
	2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; ≥ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthron	Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers	Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots
	5 Enhanced Hedgerow Management On Both Sides	• WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping; B & D plots B & D plots
	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre	• New stock proof, double fencing around existing hedges	Linears & Fence condition

	width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots
	43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • WLF connectivity • WLF – Woodland connectivity • Moth numbers • Hedge height ideally 3- 4m • Mature Double hedges	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots CONEFOR CONEFOR Invertebrate surveys Linears & D plots Linears
A study by Zeale et al. (2012) found that barbastelles had a significant preference to hunt along vegetation at the edge of water bodies (Zeale et al. 2012). Linear features like stream corridors are vital to link habitats and barbastelles will feed in woodlands before following a stream to feed over water meadows (Forestry Commission, 2005). Water meadows are	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 9A/9B. Create a new streamside corridor on improved land with tree planting on one/both sides of a watercourse	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam	Habitat mapping – linears Linears & Fence condition B, D & S plots Linears & Fence condition

highly productive of insect biomass (Greenaway, 2005) and bats foraging over wet meadows mainly prey on micromoths (Bat Conservation Trust, 2010a). A line of trees on both sides of a small stream with canopies touching creates the ideal flight line; but as a stream becomes wider, a wide line of trees on one side of the bank is more preferable (Greenaway, 2005). Tree lines should be left alongside watercourse, with only light selective felling to ensure understory remains intact (Greenaway 2005).	8 Continued management of an existing streamside corridor 173. Streamside corridor management	• Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance • Presence of woodland stream or river • Stream corridor – Woodland connectivity • Tree lined streams connected to water meadows • Moth numbers (stream corridors & water meadows)	B, D & S plots Habitat mapping CONEFOR Habitat mapping Invertebrate surveys
Light grazing has little effect on moth biomass. Old established unfertilised grasslands and water meadows are naturally highly productive of insect biomass (Greenway, 2004).	123 Lowland unimproved neutral grassland – pasture 125 Lowland unimproved neutral grassland - reversion (pasture) 134 Lowland marshy grassland - reversion (pasture)	• Sheep grazing on unimproved neutral grassland • Sheep & Cattle grazing on unimproved neutral grassland • Sward height between 10cm – 20cm • Sward height between 5cm – 20cm when not grazed by sheep • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm	Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping, X, U & Y plots
'Series of isolated trees, such as spreading willows, can be highly effective in slowing wind speeds and increasing insect availability' (Greenaway, 2005).	104 Wood pasture 13 Plant individual native trees on improved land	• Isolated trees on improved or grazed grassland • New wood pasture/isolated trees • Tree guards	Habitat mapping – points Habitat mapping Habitat mapping

	106 Historic parks and gardens	• Maintained grazing on grassland	Habitat mapping
'Freshwater is important for drinking and foraging. New ponds and pond complexes created for bats should be located in areas near to, or with good connectivity to, other important habitats for bats, such as woodlands, river corridors and wetlands.' (Pond Conservation, 2011). Pond Conservation (2011) suggest ponds should be located within 1km of woodland, river corridors, hedgerows and tree-lines.	35 Create a wildlife pond on enclosed improved land 35B Create a wildlife pond on enclosed improved land – variable size 36 Buffer existing unfenced in-field ponds	No guidance • New Ponds with an area > $25m^2$ and < $1000m^2$ • Stock proof fenced ≥10m from pond edge • New area of rough grass around pond ≥10m from pond edge • New stock proof fencing around existing ponds • <u>Ponds within 1km from Woodlands, hedges and stream/river corridors</u>	 Habitat mapping Linears and Fence condition Habitat mapping & Y plots Habitat mapping – linears Habitat mapping
Entwistle et al. (2001) suggest that old orchards should be retained as these provide bats with additional feeding opportunities. According to Entwistle et al. (2001), barbastelles have also been recorded in parks and orchards.	11 Restore a traditional orchard 12 Create a new orchard on improved land Option 172 - Orchard Management	• Area of new orchard adjacent to existing orchard • Tree protectors • Orchard grazing • Area of new orchard on improved land • Tree protectors • Varied sward -80% of grasses between 7cm & 20cm • 5-10% left uncut every year • <u>Old orchards – tree maturity</u>	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping, X & Y plots Habitat mapping Habitat mapping
Study of barbastelle bats at Pengeli forest found that over grown scrub (mainly bramble) in the near vicinity of roosts was an important feeding ground for the bats (Billington, 2003).	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub	• New area of rough grassland in field corner (Max size 0.35ha) • New length and location of stock proof	Habitat mapping Linears and fence condition

	101 Trees and scrub - establishment by Planting / 102 Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• Newly established trees and scrub • New length of stock proof fence • Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition
Field margins helps to provide a buffer against pesticide spray drift. Adding margin to arable land also helps to increase insect availability (Entwistle et al, 2001). Particularly of use of arable margins are situated next to hedgerows (English Nature, 2003).	174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• New rough grass margin on arable land • Livestock excluded	Habitat mapping Habitat mapping
Hay cutting greatly and suddenly alters local insect availability at a very susceptible time of year for pregnant barbastelle bats (Greenaway, 2005).	124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting) 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Grassland maintained by grazing and hay cutting • Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting • Grassland maintained by grazing and hay cutting • Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting • Fields shut off to livestock by 1 May	Habitat mapping Habitat mapping Habitat mapping; X & Y plot Habitat mapping Habitat mapping Habitat mapping; X ploy Habitat mapping
Unable to find evidence	Option 175 - Management of rough grassland; enclosed land	• Minimal or no scrub on grassland • At least 75% of grasses >20cm high	Habitat mapping, X plots Habitat mapping, X plots

BECHSTEIN'S BAT

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Bechstein's bat is a woodland species as deciduous woodland provides most of their habitat needs (Entwistle et al. 2001). Compositional analysis of broad habitat classes ranked broadleaved woodland and water significantly over pasture, tree-lines hedgerows and conifer plantations. Furthermore areas of broadleaved woodland with a closed canopy and well developed understorey were preferred (Schofield and Fitzsimmons, 2004). The UK wide Bechstein project found that Breeding female Bechstein's bats are predominantly found in woodlands that meet three or four of the following model criteria devised by Hill and Greenaway (2006): Broadleaf woodland particularly that dominated by oak and/or ash: At least 75% canopy cover: Native understorey present, particularly hazel and hawthorn: At least 50% understorey cover. Understorey is a key feature of woodland used by Bechstein's, particularly as understorey gives some degree of cover (Greenaway, 2004). Native understorey of hawthorn and hazel is particularly important and should be retained where possible (Miller, 2012; Kerth et al. 2001). Foraging by British Bechstein's bats largely takes place in the crowns of mature oak trees, but foraging areas are small and colony sizes are being limited due to fragmentation of suitable woodland (Durrant et al. 2009). In agreement with this, Greenaway suggests about 50 hectares of mature oak with a good understory and small streams are ideal foraging habitat	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing (deciduous) woodland • Stock excluded from woodland • Area of existing (deciduous) woodland • Area of new scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • Insect numbers (woodland) • At least 75% canopy cover and 50% understorey cover • Hazel and hawthorn in woodland understory • Ash and/or oak dominated woodland • 50ha of mature oak woodland • Woodland – woodland connectivity	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping Linears and Fence condition Invertebrate surveys Habitat Mapping, X & Y plots Habitat Mapping, X & Y plots Habitat mapping, X & Y plots Habitat mapping CONEFOR

for both juvenile and adult Bechstein's. Colony size and success is thought to be greatest when oak is the dominant woodland species (Greenaway, 2004). Roosting occurs within hollow, dead branches, rot holes or old woodpecker holes in old deciduous trees (Quine et al, 2004). The majority of roost trees have been found on the edge of the woodland close to open fields (Fitzsimons et al. 2002).			
Hedges that are similarly structured to favoured woodland (i.e tree lines) are particularly important as these provide connectivity between foraging areas (Palmer et al. 2013). Radio tracking projects in the UK have tracked individual bats foraging along hedgerows and in small woodland areas. Bats will follow hedgerows to access other woodland within a few hundred metres. Mature, large hedgerows are most favourable. Hedges should therefore be sympathetically managed and allowed to grow large if possible (Merrett 2012).	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land 2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land 3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; ≥ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m • New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; ≥ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthron • New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers	Habitat Mapping – linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots Habitat mapping - linears Linears & Fence condition B & D plots B & D plots

			B & D plots
	5 Enhanced Hedgerow Management On Both Sides	• WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping; B & D plots B & D plots
	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots
	43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots
		• WLF connectivity • WLF – Woodland connectivity • Moth numbers • Hedge height ideally 3- 4m	CONEFOR CONEFOR Invertebrate surveys Linears & D plots

		• Mature Double hedges	Linears
Foraging woodland areas are normally associated with streams (Fitzsimons et al. 2002) and Bechstein's maternity roosts in the UK have been found to usually be located within 1km of a water body (Miller, 2012). Radio-tacked bats have been found to forage along tree lined rivers within close proximity to woodland (few hundred metres). This has been shown to benefit Bechstein's when commuting and foraging outside of woodland (Merrett 2012). A study by Palmer et al. (2013) found four roost trees lined along a small river and all were situated within 550m of woodland.	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 9A/9B. Create a new streamside corridor on improved land with tree planting on one/both sides of a watercourse 8 Continued management of an existing streamside corridor 173. Streamside corridor management	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam • Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance • Stream corridor –woodland connectivity • High species richness • Tall and wide corridors	Habitat mapping – linears Linears & Fence condition B, D & S plots Linears & Fence condition B, D & S plots CONEFOR B, D & S plots Habitat mapping
Orchards found in close proximity to Bechstein bat woodland should be retained and positively managed for insects. This could be beneficial as male Bechstein's have been found at a wider range of sites, including small woodland. In addition, a male has been recorded in bat box on the edge of a small patch of orchard in Wiltshire (Merrett, 2012).	11 Restore a traditional orchard 12 Create a new orchard on improved land Option 172 - Orchard Management	• Area of new orchard adjacent to existing orchard • Tree protectors • Orchard grazing • Area of new orchard on improved land • Tree protectors • Varied sward -80% of grasses between 7cm & 20cm • 5-10% left uncut every year	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping, X & Y plots Habitat mapping

'Series of isolated trees, such as spreading willows, can be highly effective in slowing wind speeds and increasing insect availability' (Greenaway, 2005).	104 Wood pasture 13 Plant individual native trees on improved land 106 Historic parks and gardens	• Isolated trees on improved or grazed grassland • New wood pasture/isolated trees • Tree guards • Maintained grazing on grassland	Habitat mapping – points Habitat mapping Habitat mapping Habitat mapping
Unable to find evidence	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 101 Trees and scrub -establishment by Planting / 102 Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• New area of rough grassland and scrub in field corner (Max size 0.35ha) • New area of scrub in field corner • New length and location of stock proof • New area of trees and scrub • New length of stock proof fence • Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition
Unable to find evidence	123 Lowland unimproved neutral grassland – pasture / 125 Lowland unimproved neutral grassland - reversion (pasture) 134 Lowland marshy grassland - reversion (pasture) / 133 Lowland marshy grassland	• Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm – 20cm • Sward height between 5cm – 20cm when not grazed by sheep • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm	Habitat mapping Habitat mapping Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping, X, Y & U plots

Unable to find evidence	124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting)	• Grassland maintained by grazing and hay cutting • Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting	Habitat mapping Habitat mapping Habitat mapping; X & Y plot
	132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Grassland maintained by grazing and hay cutting • Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting • Fields shut off to livestock by 1 May	Habitat mapping Habitat mapping Habitat mapping; X ploy Habitat mapping
Unable to find evidence	405 Additional Management Payment - Grazing management for dung invertebrates	Minimal guidance – additional payment	

GREATER HORSESHOE BAT

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Ancient woodland is one of the key habitats for this species and has been proven to be valuable foraging habitat as well as being used key flight paths Requirement of prey items reflects the selection of favoured habitat i.e. cock chafers feed on deciduous tree leaves (Billington & Rawlinson, 2006). Wet woodland is also a major foraging habitat for lesser horseshoes as this habitat supports particularly diverse and high insect numbers (Entwistle, 2001).	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing (deciduous) woodland • Stock excluded from woodland • Area of existing (deciduous) woodland • New area of scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • <u>Insect numbers (woodland)</u> • <u>Canopy closure/cover</u> • <u>Presence of wet woodland</u>	Linears & Fence Condition Habitat mapping Habitat mapping Habitat mapping Linears and Fence condition Invertebrate surveys Habitat Mapping, X & Y plots Habitat mapping
Tall, thick Woody linear features (WLF) at least 2m high are efficient at providing a linear feature with a large abundance of insect prey using just a small area of land. Furthermore they accumulate high concentrations of insects during high winds (Longley, 2003; Ransome & Hutson, 2000). Thick hedgerows or scrub adjacent to cattle grazed pasture are also highly suitability for greater horseshoe bats as manure provides one of main source of food – dung beetles (Billington & Rawlinson, 2006). Greater horseshoes primarily forage along the edge of tree lines, woodland edges and hedgerows (Longley, 2003). For the conservation of greater horseshoes, Natural England (2003) advise that tree lines and	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land 2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; $\geq$ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m • New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots Habitat mapping – linears Habitat mapping; B & D plots

hedges are planted across large, open areas of permanent pasture to help create smaller fields which are well linked with existing hedges and woodland blocks to improve flight path connectivity. Hedges should be broad, ideally 3-6m across and 3m high to provide sheltered flight paths before dark. Finally, young saplings should be left in hedges to provide shelter and feeding perches.		• New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; $\geq$ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthron	Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; $\geq$ 5 woody species • $\leq$ 25% native conifers	Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots
	5 Enhanced Hedgerow Management On Both Sides	• WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping; B & D plots B & D plots
	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots

	43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • WLF connectivity • WLF – Woodland block connectivity • Hedge height: >2m • Hedge width: >3m • Mature hedgerows adjacent to cattle grazed pasture • Invertebrate numbers (WLF)	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots CONEFOR CONEFOR Linears & D plots Linears & D plots Habitat mapping Invertebrate surveys?
Greater horseshoes prefer to fly close to scrambling tall-herb and scrub. River and stream corridors are key flight paths used for commuting and navigation (Entwistle et al, 2001; Billington and Rawlinson, 2006).	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 9A/9B. Create a new streamside corridor on improved land with tree planting on one/both sides of a watercourse 8 Continued management of an existing streamside corridor 173. Streamside corridor management	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam • Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance • Stream corridor connectivity	Habitat mapping – linears Linears & Fence condition B, D & S plots Linears & Fence condition B, D & S plots CONEFOR

		• Stream corridor – roost connectivity • Tall and wide corridors	CONEFOR Habitat mapping
‘Freshwater is important for drinking and foraging. New ponds and pond complexes created for bats should be located in areas near to, or with good connectivity to, other important habitats for bats, such as woodlands, river corridors and wetlands.’ (Pond Conservation, 2011). Pond conservation (2011) suggest ponds should be located within 1km woodland, river corridors, hedgerows and tree-lines.	35 Create a wildlife pond on enclosed improved land 35B Create a wildlife pond on enclosed improved land – variable size 36 Buffer existing unfenced in-field ponds	No guidance • New Ponds with an area > 25m^2 and < 1000m^2 • Stock proof fenced ≥10m from pond edge • New area of rough grass around pond ≥10m from pond edge • New stock proof fencing around existing ponds • Ponds within 1km from Woodlands, hedges and Stream/river corridors	Habitat mapping Linears and Fence condition Habitat mapping & Y plots Habitat mapping - linears Habitat mapping
Old orchards (mature fruit trees) with a grazed understory can be used a hunting area by greater horseshoes particularly if use of pesticides are avoided (English Nature, 2003). Retaining old orchards, particularly adjacent to grazed pasture is beneficial as this provides additional foraging opportunities (Entwistle, 2001).	11 Restore a traditional orchard 12 Create a new orchard on improved land Option 172 - Orchard Management	• Area of new orchard adjacent to existing orchard • Tree protectors • Orchard grazing • Area of new orchard on improved land • Tree protectors • Varied sward -80% of grasses between 7cm & 20cm • 5-10% left uncut every year • Old orchards - tree maturity • Orchards adjacent to grazed pasture	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping, X & Y plots Habitat mapping Habitat mapping Habitat mapping

'Series of isolated trees, such as spreading willows, can be highly effective in slowing wind speeds and increasing insect availability' (Greenaway, 2004).	104 Wood pasture 13 Plant individual native trees on improved land 106 Historic parks and gardens	• Isolated trees on improved or grazed grassland • New wood pasture/isolated trees • Tree guards • Maintained grazing on grassland	Habitat mapping – points Habitat mapping Habitat mapping Habitat mapping
Field margins helps to provide a buffer against pesticide spray drift. Adding margin to arable land also helps to increase insect availability (Entwistle et al, 2001). This is particularly useful when arable margins are situated next to hedgerows (English Nature, 2003).	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land 174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated • New rough grass margin on arable land • Livestock excluded	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping
Light grazing has little effect on moth biomass and so should be encouraged to maintain vegetation structure, arrest succession and foster species-rich grassland. Old established unfertilised grasslands and water meadows are naturally highly productive of insect biomass (Greenway, 2004). Cattle dung is used by the Night-flying Dung beetle (*Aphodius rufipes)* to lay eggs, as well as being a food source for the adults. *Aphodius rufipes* is key prey item for lactating females and juveniles. Hence cattle grazed pasture is a valuable foraging habitat for greater	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture)	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots

horseshoe bats (Billington & Rawlison, 2006; Bat Conservation Trust, 2010). A mosaic of grazed permanent pasture and botanically diverse pasture helps to promote high densities of insects. This coupled with an abundance of tall bushy hedges, is the ideal habitat for greater horseshoe bats (English Nature, 2003)	123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture)	• Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep	Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots
	128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture)	• Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm	Habitat mapping Habitat mapping; X & U plots
	131 Conversion from arable to grassland (no inputs)	• Area of new grassland • Grassland grazed once established • Sward height at least 5cm	Habitat mapping Habitat mapping Habitat mapping, X plot
	133 Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture)	• Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm	Habitat mapping Habitat mapping, X, U & Y plots
		• <u>Numbers of dung beetles particularly Aphodius rufipes</u> • <u>Permanent pasture bordered by mature hedges</u> • <u>Cattle grazed pasture</u>	Invertebrate Survey Habitat mapping Habitat mapping
Hay meadows provide good foraging areas for preying on insects during the summer. Leaving an uncut area allows more invertebrates to survive once the hay is cut. Furthermore, grazing after a cut benefits invertebrates as they create patches of bare or disturbed ground with dung (Bug life, n.d; Vincent wildlife trust, 2014)	22 Existing hay meadows	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high • Grassland maintained by grazing and hay cutting	Habitat mapping Habitat mapping; X & Y plots Habitat mapping

	122 Lowland unimproved acid grassland - reversion (hay cutting) / 124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting) / 130 Lowland unimproved calcareous grassland - reversion (hay cutting) / 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Field shut off from livestock by 1 May every year • Between 5%-10% left uncut • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping Habitat mapping; X & Y plots
Wetland supports insect rich feeding habitat. An abundance of insect prey key for the survival of greater horseshoe bats. As such, loss of feeding areas is often due to loss of wetlands and hedges and conversion to arable land (Townsend, 2005). Marshy grassland should be retained as this habitat supports good populations of preferred insects such as crane fly (English Nature, 2003).	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing Option 143 - Lowland fen / 145 Lowland fen; reversion (pasture)	• Sward height (excluding rushes) between 5-30cm on enclosed land • Mixed grazing • Sward height (excluding rushes) between 5-30cm on enclosed land • Grazing on Lowland fen • Sward height between 10cm-80cm (except patches of moss)	Habitat mapping, X, Y & U plots Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping Habitat mapping, X & Y plots
Unable to find evidence	20. Management of Coastal and Lowland Heath / 20B. Management of Coastal and Lowland Heath With Mixed Grazing	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • ≥ 25% dwarf-shrub species on coastal heath • ≤25% of heath burnt over 5 years	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	33 Establish a wildlife cover crop on improved land	• On improved land only • 4m wide seed bed established for crop • Crop cover to be at least 80% cereals with at least one of the following; mustard, rape or linseed.	Habitat mapping Habitat mapping Habitat mapping; A & M plot

		• No maize	Habitat mapping
Unable to find evidence	Option 148 - Coastal grassland (maritime cliff and slope)	• Grassland maintained by grazing • Varied sward height	Habitat mapping
Unable to find evidence	46 - Reedbed; stock exclusion 147 - Reedbed; creation	• New stock proof fencing around reedbed • New area of reedbed	Linears and Fence condition Habitat mapping
Unable to find evidence	149 - Saltmarsh; restoration (no grazing) 150 - Saltmarsh; creation	• Livestock exclusion on existing marsh	Habitat mapping
Unable to find evidence	153 - Red clover ley	• 80% of sward is red clover	Habitat mapping, X plot
Unable to find evidence	175 Management of rough grassland; enclosed land	• Minimal or no scrub • At least 75% of grasses >20cm high	Habitat mapping, X plots Habitat mapping, X plots
Unable to find evidence	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 101. Trees and scrub - establishment by Planting 102. Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• New area of rough grassland and scrub in field corner (Max size 0.35ha) • New length and location of stock proof • New area of trees and scrub • New length of stock proof fence • Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition
Unable to find evidence	31 Unsprayed spring sown cereals retaining winter stubbles 115 Lowland dry heath with less than 50% western gorse / 116 Lowland dry heath with more than 50% western gorse	Minimal guidance	

	117 Lowland wet heath with less than 60% purple moor- grass / 118 Lowland wet heath with more than 60% purple moor-grass 119 Lowland heath habitat expansion - establishment on grassland 139 Lowland bog and other acid mires with less than 50% purple moor-grass 140 Lowland bog and other acid mires with more than 50% purple moor-grass 141 Lowland bog and other acid mires - restoration (no grazing) 142 Lowland bog and other acid mires - reversion (pasture)		

LEESER HORSESHOE BAT

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Studies of Lesser Horseshoe maternity roosts found that their roosts are chosen on basis of well-connected foraging area. Whilst blocks of mixed woodland are highly selected, hedgerows and tree lines were also important as these provided connectivity to the maternity roost and other foraging areas (Knight, 2006; Motte & Libois, 2002; Schofield, 1996). Woodland edges can act as shelter from the wind, thus reducing wind speeds. Not only does this aid economical hunting flight but edges also accumulate high concentrations of insects (Billington & Rawlinson 2006). Lesser horseshoe bats echolocation method suggests the species prefers to forage close to cluttered habitats (Billington & Rawlinson, 2006; Bontadina et al. 2002; Schofield, 1996). Numerous radio-tracking studies have shown that mixed broadleaved woodland and woodland edges are the preferred foraging habitat for this species (Knight, 2006; Motte & Libois, 2002; Schofield, 1996). Foraging by lesser horseshoes has been observed foraging in dense vegetation such as canopy of hawthorn or hazel trees, or close to the canopy of trees or hedgerows (Schofield, 1996). It is thought oak, ash, hawthorn and hazel are the main deciduous woodland species used by lesser horseshoes as sources of insect prey from (Motte & Libois, 2002; Schofield 1996). As such, protecting understorey from stock grazing protects insect availability.	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing (mixed deciduous) woodland • Stock excluded from woodland • Area of existing (mixed deciduous) woodland • New area of scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • % cover of shrub in deciduous woodland • % cover of oak & ash in deciduous woodland • Insect numbers (woodland) • Presence of wet woodland	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping Linears and Fence condition X & Y plots Habitat mapping, X & Y plots Invertebrate surveys Habitat mapping

Wet woodland is a foraging habitat also used by lesser horseshoes as this habitat supports particularly diverse and high insect numbers (Entwistle et al. 2001; Schofield & Bontadina, 1999).			
Lesser horseshoe bats actively avoid open areas and instead rely on woody linear features lines (WLF) to move between roosts and woodland feeding areas. Studies of lesser horseshoe maternity roosts found that their roosts are chosen on basis of well-connected foraging area. Whilst blocks of mixed woodland are highly selected, hedgerows and tree lines were also important as these provided connectivity to the maternity roost and other foraging areas. These woody features and appropriate herbaceous vegetation were foraged within 2-3 km of the maternity roost (Knight, 2006; Motte & Libois, 2002; Schofield, 1996). In uplands and lowland, tall unmanaged hedges adjacent to semi or unimproved wet pasture fields, improved damp or wet ground are of greater significance when within 1-3km from roost (Billington & Rawlinson, 2006; Knight 2006; Schofield, 1996). Linear features not only important for connectivity and foraging, but are also important for predator avoidance (Schofield, 1996). Studies by Knight (2006) and Schofield (1996) found Improved fields with tall unkempt hedges on one or more sides of the boundaries were significantly selected for when foraging. Hedges also act as shelters from the wind, reducing wind speeds which aids economical hunting flight, as well as being able to accumulate high concentrations of insects (Billington & Rawlinson 2006). Managed hedges have also been found to be used by lesser horseshoe bats mainly for	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land 2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land 3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; ≥ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m • New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; ≥ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthorn • New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots

commuting, albeit at a low level (Knight, 2006; Schofield, 1996).	5 Enhanced Hedgerow Management On Both Sides	• WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping; B & D plots B & D plots
	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots
	43A/43B. Double Fence and Restore Hedge Banks <u>With</u>/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots
		• <u>WLF connectivity</u> • <u>WLF – Woodland connectivity –</u> • <u>Insects numbers (WLF's)</u> • <u>WLF's bordering wet pastures</u>	CONEFOR CONEFOR Invertebrate survey? Habitat mapping

'Vegetated streams banks and bank side trees are used to move between roosts and woodland feeding areas as these provide connectivity (Billington & Rawlinson, 2006). Numerous studies have shown that lesser horseshoes forage and commute along structurally diverse vegetated riparian strips and river bank edges. However these habitat features are least selected for when there is woodland within the foraging areas (Bontadina et al. 2002; Motte & Libois, 2002).	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 9A/9B. Create a new streamside corridor on improved land with tree planting on one/both sides of a watercourse 8 Continued management of an existing streamside corridor 173. Streamside corridor management	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam • Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance • Stream corridor connectivity • Stream corridor – woodland connectivity • Species rich • Structural diversity	Habitat mapping – linears Linears & Fence condition B, D & S plots Linears & Fence condition B, D & S plots CONEFOR CONEFOR S & P plots S & P plots
'Freshwater is important for drinking and foraging. New ponds and pond complexes created for bats should be located in areas near to, or with good connectivity to other important habitats for bats, such as woodlands, river corridors and wetlands.' (Pond Conservation, 2011). Pond conservation (2011) suggests ponds should be located within 1km woodland, river corridors, hedgerows and tree-lines.	35 Create a wildlife pond on enclosed improved land 35B Create a wildlife pond on enclosed improved land – variable size 36 Buffer existing unfenced in-field ponds	No guidance • New Ponds with an area > $25m^2$ and < $1000m^2$ • Stock proof fenced $\geq$10m from pond edge • New area of rough grass around pond $\geq$10m from pond edge • New stock proof fencing around existing ponds • Ponds within 1km from Woodlands, hedges and Stream/river corridors	 Habitat mapping Linears and Fence condition Habitat mapping & Y plots Habitat mapping - linears Habitat mapping

Management practises recommended by Knight (2006) & Entwistle et al. (2001) suggest that old orchards should be retained as these provide additional feeding opportunities.	11 Restore a traditional orchard 12 Create a new orchard on improved land Option 172 - Orchard Management	• Area of new orchard adjacent to existing orchard • Tree protectors • Orchard grazing • Area of new orchard on improved land • Tree protectors • Varied sward -80% of grasses between 7cm & 20cm • 5-10% left uncut every year	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping, X & Y plots Habitat mapping
'Series of isolated trees, such as spreading willows, can be highly effective in slowing wind speeds and increasing insect availability' (Greenaway, 2004).	104 Wood pasture 13 Plant individual native trees on improved land 106 Historic parks and gardens	• Isolated trees on improved or grazed grassland • New wood pasture/isolated trees • Tree guards • Maintained grazing on grassland	Habitat mapping – points Habitat mapping Habitat mapping Habitat mapping
Light grazing has little effect on moth biomass and should be encouraged to maintain vegetation structure, species richness and arrest succession. Old established unfertilised grasslands and water meadows are naturally highly productive of insect biomass (Greenway, 2004). A study of lesser horseshoe bats found pastures were the preferred foraging habitat compared to arable fields. It is therefore suggested that permanent pasture is retained or created within the near vicinity of a roost, particularly if associated with woodyland (Knight, 2006).	15 Grazed permanent pasture with no inputs / 15C Grazed permanent pasture with no inputs and mixed grazing 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland	• Permanent pasture maintained • Grazing/ Mixed grazing • Grassland maintained by grazing • 75% grasses and herbs between 3cm-20cm in height between May and September • Grassland maintained by grazing	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping;

	unimproved neutral grassland - reversion (pasture) 128 - Lowland unimproved calcareous grassland / 129. Lowland unimproved calcareous grassland - reversion (pasture) 131 - Conversion from arable to grassland (no inputs) 133 - Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture)	• In sheep grazed areas, varied sward height maintained between 10cm – 20cm • In none sheep grazed areas, varied sward height maintained between 5cm – 20cm • Grassland maintained by grazing • 75% grasses and herbs between 3cm-50cm in height between May and September • Establishment of new grassland • Grassland maintained by grazing • Sward height at least 5cm • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm • Pasture associated with hedges and/ or woodland	Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping; X plots Habitat mapping Habitat mapping, X, U & Y plots Habitat mapping
Field margins helps to provide a buffer against pesticide spray drift. Adding margin to arable land also helps to increase insect availability (Entwistle et al, 2001), particularly arable margins which are situated next to hedgerows (English Nature, 2003).	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping

	174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• No grazing once established • Can be rotated • New rough grass margin on arable land • Livestock excluded	Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping
Well-developed field boundaries such as areas of trees and scrub can provide links between roosts and foraging areas provided they are connected to a network of hedges and woodland (Billington & Rawlinson, 2006). Scrub and overhanding vegetation also provides a source of insects for foraging bats (Entwistle, 2001).	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 101 Trees and scrub - establishment by Planting / 102 Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• New area of rough grassland and scrub in field corner (Max size 0.35ha) • New length and location of stock proof • New area of trees and scrub • New length of stock proof fence • Existing area of scrub • New stock proof fencing around areas of scrub • Scrub/tree connectivity to hedges and woodland	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition
Unable to find evidence	22 Existing hay meadows	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping; X & Y plots
Unable to find evidence	Option 143 - Lowland fen / 145 – Lowland fen; reversion (pasture)	• Grazing on Lowland fen • Sward height between 10cm-80cm (except patches of moss)	Habitat mapping Habitat mapping, X & U plots
Unable to find evidence	146 - Reedbed; stock exclusion 147 - Reedbed; creation	• New stock proof fencing around reedbed • New area of reedbed	Linears and Fence condition Habitat mapping

Unable to find evidence	21. Management of grazed saltmarsh 21B. Management of grazed saltmarsh with mixed grazing 149. Saltmarsh; restoration (no grazing) 150. Saltmarsh; creation	• Saltmarsh grazing by cattle, sheep, goats or ponies • Saltmarsh grazing by cattle, sheep, goats or ponies • Livestock exclusion on existing marsh • Area of new saltmarsh	Habitat mapping Habitat mapping Habitat mapping Habitat mapping
Unable to find evidence	153 - Red clover ley	• 80% of sward is red clover	Habitat mapping, X plot
Unable to find evidence	175 Management of rough grassland; enclosed land	• Minimal or no scrub • At least 75% of grasses >20cm high	Habitat mapping, X plots Habitat mapping, X plots
Unable to find evidence	20. Management of Coastal and Lowland Heath / 20B. Management of Coastal and Lowland Heath With Mixed Grazing	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • ≥25% dwarf-shrub species on coastal heath • ≤25% of heath burnt over 5 years	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing	• Sward height (excluding rushes) between 5-30cm on enclosed land • Sheep & Cattle grazing on marshy grs (enclosed land) • Sward height (excluding rushes) between 5-30cm on enclosed land	Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping, X, Y & u plots
Unable to find evidence	31 Unsprayed spring sown cereals retaining winter stubbles	• On improved land only • Natural regeneration of grass and broadleaved plants after harvest • No grazing between harvest and 1st January	Habitat mapping A & M plots Habitat mapping Unlikely to be mapped

		• Can be rotated	
Unable to find evidence	115 Lowland dry heath with less than 50% western gorse / 116 Lowland dry heath with more than 50% western gorse 117 Lowland wet heath with less than 60% purple moor- grass / 118 Lowland wet heath with more than 60% purple moor-grass 119 Lowland heath habitat expansion - establishment on grassland 139 Lowland bog and other acid mires with less than 50% purple moor-grass 140 Lowland bog and other acid mires with more than 50% purple moor-grass 141 Lowland bog and other acid mires - restoration (no grazing) 142 Lowland bog and other acid mires - reversion (pasture)	Minimal guidance	

DORMOUSE			
Evidence obtained from Literature	**Target Species and Glastir Measures**	**Specific Response Variables**	**GMEP Survey Data That Captures Measure or Target**
Dormice are highly arboreal (Bright, 1998) and are largely associated with diverse deciduous woodland and scrub with a diverse and abundant understorey. It is therefore important that dormice can freely move from tree to tree and tree to understory without having to go to the ground (Bright et al. 2006). Dormouse abundance is often highest in mid-aged coppice, 6–10 years of re-growth (Bright and Morris, 1990). Best canopy trees are oaks with hazel and bramble providing the best understory providing they are not too heavily shading to prevent fruiting. The larger the woodland size, the higher the possibility of dormouse being present within a woodland, particularly if over 50ha in size (Bright et al, 2006). Coppice woodland is thought to be optimal habitat for dormice as this provides glades of open canopy, re-growth and a places to hibernate after an arboreal summer. Cessation of coppicing is thought to be one of the reasons for dormouse population decline as this ultimately results in suppression of re-growth in the understory due to heavy shading (Bright and Morris, 1990; Bright et al, 2006). Dormouse feed on largely ephemeral food sources i.e. tree/shrub flowers, fruits and phytophagous insects. Hazel is the principle food source providing insects and hazel nuts, used to fatten up dormice for hibernation. However, different species provide different food source throughout the year, therefore dormice require a large variety of tree and shrub species to provide	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing (deciduous) woodland • Stock excluded from woodland • Area of existing deciduous woodland • Area of new scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • % oak – canopy • % hazel and bramble – understory • Woodland (deciduous& coniferous) between 20ha and >50ha • Coppice woodland • Species rich	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping Linears and Fence condition Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping

them with a continuous food supply throughout the year. Trees of value include hornbeam, yew, ash, sycamore, oak, wayfairing tree, birch, sweet chestnut, birch, blackthorn and hawthorn. Shrubs of value include bramble, broom and honeysuckle (Bright & Morris, 1990; Bright et al, 2006). Browsing by stock suppresses vegetation regeneration and fruiting, stock should therefore be excluded from woodland with dormice to ensure sufficient food sources (Forest research, 2007; Bright et al. 2006).			
Woody linear features (WLF) may be important in facilitating dispersal between woodlands and maintaining the integrity of dormouse (meta) populations, particularly in small, fragmented habitats (Bright, 1998). Dormice are known to breed and nest in species rich hedges, particularly where they provide connectively to large woodlands (Bright et al. 2006; Hedgelink n.d). Connectivity is key as well connected hedges, woodland and patches of scrub facilitate movement through the landscape and also allows adults to forage and nest with ease (Hedgelink, n.d). Shrub diversity is linked to dormouse abundance, as such, hedgerows need to species rich particularly as dormice tend to travel less than 70m from their nests and need a diverse and constant food source throughout the seasons (Bright et al. 2006). Dormouse shown to be averse to crossing gaps (even narrow 1m-3m gaps) in hedgerows and gaps in hedges likely to constrain movement (Bright, 1998). Hedges need to be thick and wide to provide habitat connections. Laying, coppicing and the use of fencing to prevent stock damage seen as best management practise to restore hedges for gappy hedges for dormice (Bright et al. 2006).	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; $\geq$ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots
	2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; $\geq$ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthorn	Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing	Habitat mapping - linears Linears & Fence condition B & D plots

As part of good hedgerow management, Bright et al. (2006) suggest hedges should be maintained at a height of 3m, but probably 4m.	5 Enhanced Hedgerow Management On Both Sides 6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing 42B. Hedgerow restoration without fencing 43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• Species richness ; $\geq$ 5 woody species • $\leq$ 25% native conifers • WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m • New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m • Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness • New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • WLF connectivity	B & D plots B & D plots Habitat mapping; B & D plots B & D plots Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots D plots D plots Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots CONEFOR

		• WLF – Woodland Connectivity • % Hazel • % Bramble, honeysuckle, blackthorn, hawthorn & broom • WLF height 3m-4m	CONEFOR Habitat mapping; B & D plots Habitat mapping; B & D plots Habitat mapping
Scrub, being made up of woody species is a favourable habitat of dormice. Scrub can allow dormice to inhabit small areas of Ancient woodland and PAWS sites as they provide connectivity. Young growth stands are considered good habitat for dormice, particularly if species rich. The long term aim is for scrub to develop into woodland which is largely achieved by removing access to grazing stock (Bright et al, 2006).	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 101 Trees and scrub - establishment by Planting / 102 Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• New area of rough grassland and scrub in field corner (Max size 0.35ha) • New length and location of stock proof • New area of trees and scrub • New length of stock proof fence • New stock proof fencing around existing areas of scrub • Scrub – WLF connectivity • Scrub – woodland connectivity	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition Habitat mapping CONEFOR CONEFOR

GREAT CRESTED NEWT

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Great crested newts (GCN) prefer deciduous woodland with vegetated or shrubby ground cover and a considerable amount of leaf litter. Dead wood is also valuable as this provides a refuge in hot/dry conditions or when overwintering and foraging outside of breeding season. (Malmgren, 2002; Mullner, 2001). Deciduous woodland appears to support higher densities of newts compared to coniferous woodland (Langton et al. 2001). Numerous studies have shown that GCN have a preference for moving to woodland when leaving a close-by pond in the summer (Malmgren, 2002; Mullner, 2001). The value of woodland is maximised when it occurs together as a mosaic with semi-natural grassland and ponds (Langton et al, 2001).	100. Woodland - stock exclusion 24. Allow woodland edge to develop out into adjoining improved land	• Length of new stock-proof fencing bordering existing (deciduous) woodland • Stock excluded from woodland • Area of existing (deciduous) woodland • Area of new woodland on improved land • New length and location of stock proof fence • Pond-Woodland connectivity • Pond, woodland, grassland mosaic • Woodland litter • Woodland understory cover	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping Linears and Fence condition Habitat mapping Habitat mapping X & Y plots X & Y plots
'Hedges provide additional foraging and dispersal habitat, particularly on agricultural intensive land. Hedge banks also increase the surface area of land, provide a sheltered microclimate, and often have mammal burrows that newts may share.' (Langton et al, 2001). A study by Joly et al. (2001) found a negative relationship between hedgerow length and newt abundance thus suggesting hedgerows do not provide a substitute for terrestrial habitat. Instead, hedges act as corridors between ponds providing additional foraging and dispersal habitat particularly on agricultural intensive land (Langton et al, 2001).	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land 2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; $\geq$ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m • New earth bank at least 0.75m high and 0.75m wide	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots Habitat mapping – linears Habitat mapping; B & D plots

	3 Create a wildlife corridor – established woody strip Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing 42B. Hedgerow restoration without fencing 43A/43B. Double Fence and Restore Hedge Banks <u>With</u>/without Planting	• WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; ≥ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthorn • New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers • New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m • Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness • New stock proof, double fencing around existing hedges	Linears & Fence condition Habitat mapping – linears B & D plots B & D plots Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots D plots D plots Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots

		• New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • <u>WLF adjacent to rough grassland</u> • <u>Pond-Rough grassland -WLF – Woodland connectivity</u>	B & D plots Habitat mapping Habitat mapping
Great crested newts mainly rely on ponds for breeding, although slow-running streams may be used (Forestry commission, 2013; Edgar & Bird, 2006). River banks/riparian strips can be used as habitat corridors between ponds, thus providing connectivity through the landscape, and preventing isolation of metapopulations (Langton et al. 2001).	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 9A/9B. Create a new streamside corridor on improved land with tree planting on one/both sides of a watercourse 8 Continued management of an existing streamside corridor 173. Streamside corridor management	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam • Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance	Habitat mapping – linears Linears & Fence condition B, D & S plots Linears & Fence condition B, D & S plots
Ponds are essential for most newts as pond is where they congregate more or less every year for breeding (Mullner, 2001). Courtship and display by adult newts happens in open pond margins. Egg larvae are laid on floating and submerged marginal vegetation, and larvae develop and feed for invertebrates in all zones of the pond (Langton et al. 2001). The closer the new pond is from an existing colonised pond (ideally <500m), the more likely a new pond will be colonised (Langton et al. 2001; Oldham et al. 2000). Optimum pond size is between 500 and 750m^2 (Oldham	35 Create a wildlife pond on enclosed improved land 35B Create a wildlife pond on enclosed improved land – variable size 36 Buffer existing unfenced in-field ponds	No guidance • New Ponds with an area > 25m^2 and < 1000m^2 • Stock proof fenced $\geq$10m from pond edge • New area of rough grass around pond $\geq$10m from pond edge	 Habitat mapping Linears and Fence condition Habitat mapping & Y plots Habitat mapping - linears

et al. 2000). Key feature of pastoral farmland to provide best chance for GCN is that inter-pond distances should low (Langton et al. 2001). Great crested newt exhibit metapopulation dynamics. Good terrestrial habitat (i.e. rough grassland) which allows newts to readily disperse, particularly to surrounding pond is essential to ensure genetic diversity (Oldham et al. 2000; Wright, 2007). Good quality habitat around a new pond (allowed to development as result of fencing) also gives newts a choice of direction when leaving the water (Langton et al. 2001). Water bodies which support submerged and emergent vegetation as well as an abundant and diverse invertebrate community (i.e. may fly larvae and water shrimp) are seen to be of good quality for GCN larvae (Oldham et al. 2000).		• New stock proof fencing around existing ponds • Pond-pond distance (<500m) • Pond-Rough grassland -WLF – Woodland- Connectivity • Ideal Pond size; 500 - 750m^2 • Presence of submerged & emergent macrophytes around pond edge • Good water quality • No pond fish • Pond Invertebrates	Habitat mapping Habitat mapping Habitat mapping RHS survey RHS survey RHS survey RHS survey
Arable land imposes foraging and distribution restrictions due to use of pesticide use and intensive farming practises such as ploughing and harrowing. However, rough grassland with dense tussocks provide areas for movement, cover and food (Langton et al, 2001). Grass margins increase floral diversity and therefore enhance insect prey (Wright, 2007). Rough grass buffers can also help to protect watercourses and ponds from the effects of run-off and spray drift (Wright, 2007). Threats to GCN include eutrophication of ponds (Edgar & bird, 2006). Rough grass buffers can help to protect watercourses and ponds from the effects of run-off and spray drift (Wright, 2007). Natural England is currently funding research on the use of buffer strips in their agri-scheme. Whilst buffers could provide cover/foraging areas for newts around edges of fields and connectivity, there management timing is an issue,	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land 27 Fallow margins	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated • New fallow crop margin adjacent to cereals, oil seed rape, linseed, maize or roots • Between 2-8m wide	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Unlikely to be measured

particularly if buffer zones are rotational and not permanent (Liz Howe Pers. comm).		• Can be rotated • Pond – rough grass connectivity • Tussocky vegetation • Vegetation height	Habitat mapping Habitat mapping; A or M plot Habitat mapping; A or M plot
Good terrestrial habitat (i.e. rough grassland) which allows newts to readily disperse, particularly to surrounding ponds is essential to ensure genetic diversity (Oldham et al. 2000; Wright, 2007). Adults usually occupied surrounding habitat within 250-500m of ponds (Edgar & Bird, 2006; Langton et al. 2001). Grassland management should aim to provide floristically-rich, invertebrate-rich and structurally varied habitat. To be maintained as grassland the sward needs to be cut or lightly grazed at least annually (Langton et al. 2001). Permanent rough/rank (especially tussocky) grassland is particularly suitable as this provides refuge throughout the year (Edgar & Bird, 2006; Langton et al. 2001)	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture) 128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture) 131 Conversion from arable to grassland (no inputs)	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep • Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm • Area of new grassland • Grassland grazed once established • Sward height at least 5cm	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping, X plot

	133 Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture)	• Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm • Tussocky grassland	Habitat mapping Habitat mapping, X, U & Y plots Habitat mapping
Scrub is important on farms where little or no woodland exists in the near vicinity of ponds (Wright, 2007).	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 101. Trees and scrub - establishment by Planting / 102. Trees and scrub - establishment by natural regeneration 103 Scrub - stock exclusion	• New area of rough grassland and scrub in field corner (Max size 0.35ha) • New length and location of stock proof • New area of trees and scrub • New length of stock proof fence • Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition Habitat mapping Linears and fence condition
Good terrestrial habitat (i.e rough and tussocky grassland) allows newts to readily disperse, particularly to surrounding ponds which is essential to ensure genetic diversity (Oldham et al. 2000). Rough, tussocky grassland also provides food and may be used as refuge in hot, dry conditions.	Option 175 - Management of rough grassland; enclosed land	• Sward height >20cm • Tussocky grassland • Rough grs-pond connectivity	Habitat mapping, X plots Habitat mapping
Morecambe Bay and Glan-traeth, Isle of Anglesey both have coastal sand dune systems and waterbodies. Both are designated as SAC’s partly due to the presence of great crested newts. Light grazing at Glan-traeth helps to maintain open terrestrial habitat for GCN adults.	25 Management of sand dunes / 25B Management of sand dunes with mixed grazing	• Grazing with cattle, sheep, goats or ponies • Varied sward height	Habitat mapping
Grassland management should aim to provide floristically-rich, invertebrate-rich and structurally varied habitat. To be maintained as grassland the sward	104 Wood pasture 106 Historic parks and gardens	• Isolated trees on improved or grazed grassland • Maintained grazing on grassland	Habitat mapping – points & polygons Habitat mapping

need to be cut or lightly grazed at least annually (Langton et al. 2001).		• Ponds in parkland	Habitat mapping
Permanent rough/rank (especially tussocky) grassland particularly suitable as this provides refuge throughout the year (Edgar & Bird, 2006; Langton et al. 2001) Good terrestrial habitat (i.e rough and tussocky grassland) allows newts to readily disperse, particularly to surrounding ponds which is essential to ensure genetic diversity (Oldham et al. 2000).	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing	• Sward height (excluding rushes) between 5-30cm on enclosed land • Sheep & Cattle grazing on marshy grs (enclosed land) • Sward height (excluding rushes) between 5-30cm on enclosed land • Presence of marshy grassland • Tussocky grassland	Habitat mapping, X, Y & Uplots Habitat mapping Habitat mapping, X, Y & U plots
Unable to find evidence	109 Calaminarian grassland	• Grazing • Sward height between 2cm – 5cm	Habitat mapping Habitat mapping, X & Y plots
Unable to find evidence	143 Lowland fen 145 Lowland fen - reversion (pasture 144 Lowland fen - restoration (no grazing)	• Sheep/Cattle grazing on Lowland fen • Sward height between 10cm-80cm • New stock proof fence around fence	Habitat mapping Habitat mapping, X & U plots Linears and Fence condition
Unable to find evidence	Option 146 - Reedbed; stock exclusion Option 147 - Reedbed; creation	• New stock proof fencing around reedbed • New area of reedbed	Linears and Fence condition Habitat mapping
Unable to find evidence	14 Commit to 100% slurry injection 14B Commit to 75% slurry injection 17 Blanket Bog 157 Buffer zones to prevent erosion and run-off from grassland - ditch landscapes / 158 Buffer zones to prevent erosion and run-off from land under arable cropping 403/404 Add' Management Payment - Re- wetting / 405 Additional Management Payment - Grazing management for dung invertebrates	Minimal guidance	

RED SQUIRREL

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Study of woodland fragmentation in Sweden showed in years with low densities of red squirrel, the species occurred mainly in larger woods with a preference towards large areas of coniferous trees (30ha). Whilst smaller and/or low quality woods tend to be occupied when situated close to permanently inhabited woodland and, connected by hedgerows within 200-600m (Van Apeldoorn et al. 1994). In Belgium it was found (through radio telemetry data) that tree rows and hedgerows bordering meadows and fields were used by juveniles to disperse from one small, fragmented woodland patch to another. Furthermore, during late summer-autumn, mainly adult males were found to move between nearby small woods (<350m apart) using hedgerows and tree lines not only for movement, but also to forage due to the abundance of hazelnuts, berries and acorns (Wauters et al. 1994). Verboom & Van Apeldoorn (1990) suggest red squirrel occurrence significantly increases when the amount of surrounding woods and/or hedgerows increase.	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; $\geq$ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots Habitat mapping – linears
	2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; $\geq$ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthron	Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; $\geq$ 5 woody species • $\leq$ 25% native conifers	Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots
	Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre		Linears & Fence condition Habitat mapping - Linears

	width (1 metre from centre) / 42A Hedgerow Restoration With Fencing 42B. Hedgerow restoration without fencing 43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m • Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness • New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • WLF – small coniferous woodland block connectivity	B & D plots Habitat mapping; B & D plots B & D plots D plots D plots Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots CONEFOR connectivity modelling.
The probability of red squirrel occurrence significantly increases when a woodland is situated close to a large, permanently inhabited wood (Verboom & van Apeldoorn, 1990). Ideally, the shape of a red squirrel forest should be round, rather than long a thin to minimise the movement of grey squirrels. Furthermore, boundary areas of at least 3km comprised of coniferous forest or	100. Woodland - stock exclusion 24 Allow woodland edge to develop out into adjoining improved land	• Length of stock-proof fencing bordering existing (coniferous) woodland • Stock excluded from woodland • Area of existing (coniferous) woodland	Linears & Fence Condition Habitat mapping Habitat mapping - polygons Habitat mapping

open land should be established around woodland to act as a buffer to greys (Lurz et al, 2004). The population ecology of red squirrels is driven by sufficient food resources, largely the temporal and spatial availability of tree seeds (Gurnell et al, 2002; Lurz et al, 1997). A radio-tracking study at Theftford forest showed that mixed conifer plantations >34 years old were preferred the habitat for red squirrels, whilst mixed conifers <25yrs were significantly avoided. Thinned, open stands of trees were also avoided. The study therefore highlighted that forests becomes more suitable for red squirrels with age. (Gurnell et al. 2002). Newly planted trees will not produce significant seed crops for at least 30 years after planting (Pepper & Patterson, 1998). Tree species to be planted as part of prescription are not specified. Oak, beech, sycamore, chestnut and hazel (large seeded species) should not be planted as these are the food plants of the grey squirrel (Wales squirrel Forum, 2009; Pepper and Patterson, 1998). If broadleaves are planted this should be confined to willow, aspen, birch and rowan (small seeded species). Seed-producing areas should be connected by continuous strips of trees to prevent isolation and facilitate movement between them (Lurz et al, 2004).	40 Management of existing fence on stock excluded woodland	• New area of scrub/woodland on improved land next to existing woodland • New length and location of stock proof fence • Existing stock proof fence maintained • Stock excluded from woodland • Presence of grey squirrel • Existing area of mixed coniferous woodland • Woodland shape (round) • Small seeded trees – conifers, willow, aspen, birch and rowan	Linears and Fence condition Linears and fence condition Habitat mapping Not measured Habitat mapping Habitat mapping Habitat mapping, X plots

WATER VOLE

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Change in both land use and riparian habitat management has resulted in habitat loss and fragmentation causing isolation of water vole populations (Strachen & Moorhouse, 2006). In the UK, lowland water voles have a preference wide swaths of dense riparian vegetation growing from soft banks alongside water courses; rocky banks are generally avoided. Riparian vegetation represents both shelter and food for water voles; thus increasing the width over a given length may lead to lower predation risk, increased survival rate and increased food abundance (Moorhouse et al. 2009; Strachen & Moorhouse, 2006). Water voles are known to eat over 200 different types of plants (particularly sedges, grasses and rushes) and do not tend to move more than 1-2m from the water edge (Gwent Wildlife Trust; Stoddart, 1970). A study by Moorhouse et al. (2009) found an increase in the abundance of suitable vegetation (e.g. riparian vegetation) of up to 300cm^2 per m of can increase water vole survival rate (Moorhouse et al. 2009). Riparian vegetation should be allowed to grow tall, particularly as voles tends to select sites with grass tussocks and emergent plants. As such, lowland river systems and riparian habitats which support water vole colonies should be protected from excessive grazing. The erection of stock proof fencing either side of a water course will therefore prevent trampling by stock and allow buffer strips either side of the water course to develop. (Strachen & Moorhouse, 2006).	7A/B Create a streamside corridor on improved land on one/both side of a watercourse 8 Continued management of an existing streamside corridor 173. Streamside corridor management	• New stream side corridor on improved land • New stock proof fence adjacent to stream corridor • Removal of Japanese knotweed and Himalayan balsam • Fencing maintained to exclude stock • Removal of Japanese knotweed and Himalayan balsam No guidance • <u>Continuous length of riparian vegetation</u> • <u>Species rich</u> • <u>Tall, tussocky, non-woody, riparian vegetation</u> • <u>1-2m wide riparian corridor</u> • <u>Mature willows adjacent to watercourse (mink indicator)</u> • <u>Low cover of streamside bramble (mink indicator)</u>	Habitat mapping – linears Linears & Fence condition B, D, S & P plots Linears & Fence condition B, D, S & P plots Habitat mapping S & P plots S & P plots Habitat mapping Habitat mapping – points Habitat mapping; S & P plots

Mink are often associated with dense scrub and woodland adjacent to water courses. Furthermore, hollow, mature trees, especially willow are used as breeding/nursery dens and bramble thickets along water courses are used by minks for cover when foraging (Strachen & Moorhouse, 2006; Carter & Bright, 2003).			
A small number of ponds in close proximity is favourable for water voles (Strachen & Moorhouse, 2006). Ideally, new ponds should be located as near as possible (up 1km) from existing water vole colonies, particularly as ponds help to link and extend wetland complexes. Furthermore, ponds created for water voles should be 1m deep and no wider than 10m largely because water voles do not like to swim more than 10m across open water. Around the edges, pond margins need to be at least 2m wide and well covered with tall grasses and herbs (Pond conservation, 2010). However, management IS needed every few years to ensure trees are not over shading the pond and out competing more favourable vegetation (Pond conservation, 2010). Off-stream ponds with marginal vegetation along waterways may be particularly valuable for water voles as these can provide a refuge area during flooding, as well as providing linkage between isolateD populations (Strachen & Moorhouse, 2006).	35 Create a wildlife pond on enclosed improved land 35B Create a wildlife pond on enclosed improved land – variable size 36 Buffer existing unfenced in-field ponds	No guidance • New Ponds with an area > 25m^2 and < 1000m^2 • Stock proof fenced ≥10m from pond edge • New area of rough grass around pond ≥10m from pond edge • New stock proof fencing around existing ponds • Ponds within 1km from Woodlands, hedges and Stream & river corridors	 Habitat mapping Linears and Fence condition Habitat mapping & Y plots Habitat mapping - linears Habitat mapping
Carter & Bright (2003) found predation rates of water vole by American mink (a major threat to water vole populations) strongly declined with increasing distance of burrows from main water channels (>10m wide). Reed beds therefore appeared to be an effective refuge from predation as they provide habitat away from features associated with mink such as scrub and ditches. Reedbeds may also support source populations	146 - Reedbed; stock exclusion 147 - Reedbed; creation	• New stock proof fencing around reedbed • New area of reedbed • Area of reedbed >10m wide	Linears and Fence condition Habitat mapping Habitat mapping

that are likely to help increase the size and viability of metapopulations in the surrounding landscape (Hardman & Harris, 2010; Carter & Bright, 2003). In Stodmash NNR, Kent; water voles still thrive in the large reedbeds even though mink are thought to have been resident for 30 years (Birght & Carter, 2000).			
Water pollution is one of the main threats to water voles (White et al. 1997). However rough grass buffer strips have ability to intercept run-off and spray drift before it reaches water courses and other habitats (Wright, 2007). A water vole scheme working with farmers in Chichester created 61km of six-metre wide buffer strips as part of the English agri-envrionment scheme. Many of the buffers were targeted beside ditches and watercourses which not only helps protect riparian strips, as well as creating links for water voles between farms (Strachen & Moorhouse, 2006).	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land 174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• New rough grass margin between 2-8m on arable land • No grazing once established • Cannot be rotated • New rough grass margin between 2-8m on arable land • No grazing once established • Can be rotated • New rough grass margin on arable land • Livestock excluded	Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping
An extensive area of marsh (584ha) studied in Somerset found that grazed marshes can provide refuge for water voles from mink predation. This was thought to be due to the avoidance of open terrestrial habitat by mink when attempting to access channels and ditches. Furthermore, the narrow ditches which run through the marsh may also not provide sufficient enough water depth for mink to escape by diving when attacked by predators (Macpherson & Bright, 2010).	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing	• Sward height (excluding rushes) between 5-30cm on enclosed land • Mixed grazing • Sward height (excluding rushes) between 5-30cm on enclosed land • <u>Presence of marshy grassland</u> • <u>Presence of narrow, water filled ditches</u>	Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping, X, Y & U plots

Unable to find evidence	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture) 128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture) 131 Conversion from arable to grassland (no inputs) 133 Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture)	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep • Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm • Area of new grassland • Grassland grazed once established • Sward height at least 5cm • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping, X plot Habitat mapping Habitat mapping, X, U & Y plots

Unable to find evidence	104 Wood pasture 106 Historic parks and gardens	• Isolated trees on improved or grazed grassland • Maintained grazing on grassland	Habitat mapping – points & polygons Habitat mapping
Unable to find evidence	20. Management of Coastal and Lowland Heath / 20B. Management of Coastal and Lowland Heath With Mixed Grazing	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • ≥25% dwarf-shrub species on coastal heath • ≤25% of heath burnt over 5 years	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	143 - Lowland fen / 145 - Lowland fen; reversion (pasture)	• Grazing on Lowland fen • Sward height between 10cm-80cm (except patches of moss)	Habitat mapping Habitat mapping, X & U plots
Unable to find evidence	122 Lowland unimproved acid grassland - reversion (hay cutting) / 124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting) / 130 Lowland unimproved calcareous grassland - reversion (hay cutting) / 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Grassland maintained by grazing and hay cutting • Field shut off from livestock by 1 May every year • Between 5%-10% left uncut • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plots
Unable to find evidence	22 Existing hay meadows	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping; X & Y plots

Unable to find evidence	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping Habitat mapping
Unable to find evidence	14 Commit to 100% slurry injection 14B Commit to 75% slurry injection 16 Upland heath 17 Blanket Bog 18 Upland grassland 117 Lowland wet heath with less than 60% purple moor grass / 118 Lowland wet heath with more than 60% purple moor-grass 119 Lowland heath habitat expansion - establishment on grassland 139 Lowland bog and other acid mires with less than 50% purple moor-grass 140 Lowland bog and other acid mires with more than 50% purple moor-grass 141 Lowland bog and other acid mires - restoration (no grazing) 142 Lowland bog and other acid mires - reversion (pasture)	Minimal or no guidance	

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BROWN BANDED CARDER BEE – *Bombus humilis*

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Bombus humilis one of the long-tongued bumblebee species that emerges relatively late in the season (May) and is associated with tall but open flower –rich grasslands where it establishes nests on the surface of the ground (Claire Carvell pers comms). Hedges can be an important part of the landscape; providing hedges are not intensively managed or degraded by herbicides. Uncropped areas of farmland i.e. hedgerows bases may provide flowers throughout the season for foraging bees. (Goulson, 2010). Carvell et al .(2006) also suggest that sympathetic management of vegetation along hedgerows edges could also encourage plants such as *Ajuga reptans* and *Lamium album*, both of which provide spring forage. However these are not likely to be required by this species until May. Bumblebee working group (2002) similarly recognised that hedge-bottom plants such as labiates in less intensive agricultural situations are important forage components for long-tongue bumblebee species.	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; ≥ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots
	2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; ≥ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthorn	Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers	Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots

	5 Enhanced Hedgerow Management On Both Sides	• WLF maintained at least 2m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Habitat mapping; B & D plots B & D plots
	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots
	43A/43B. Double Fence and Restore Hedge Banks <u>With</u>/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • <u>Presence of Labiates in hedgerows</u> • <u>Connectivity to flower rich grassland</u>	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots
One of the major agricultural changes in Britain is the loss of red clover leys (Goulson, 2010), yet red clover is	153 - Red clover ley	• Area of new red clover ley • $\geq$ 80% of sward is red clover	Habitat mapping, X plot

one of the most important food plants of *B.humilis* & B. *sylvarum* (Hymettus ltd, 2006). It has also been found that the Fabaceae family is disproportionally favoured as forage plants (Goulson, 2010; Connop, 2008; Saunders, 2008). Knowing this, the creation of red clover leys therefore has the potential to encourage the expansion of this species, particularly as red clover often flowers late into the summer (Bumblebee conservation trust, n.d).			
B. humilis has undergone a major decline in its distribution, most remaining populations being on extensive areas of coastal grassland along the southern and western coasts of England and Wales (Bwars, 2014). Recent national records have found the remaining populations of *B humilis* & *B.sylvarum* have a coastal distribution (Connop 2007; Buglife, n.d). Main habitat *of B.humilis* is in Devon and Cornwall. Thought to be due to the extensive area of semi-natural heath / grassland on the northern coastal cliff tops which are kept from the succession of scrub by the exposed climate and thin soils. Where there is heath, it is generally more open with mosaics of grassland species including Betony *Stachys officinalis*, Saw-wort *Serratula tinctoria* and Knapweed *Centaurea nigra* (Saunders 2008). Although this habitat in some cases becomes very narrow, it does form a long, continuous strip which fulfils the requirement for the species to have large areas of high quality forage (Saunders, 2008). Grazing plays a key role in maintaining the abundance and species richness associated with bumblebee forage plants. Cattle are particularly suitable for bee conservation as their grazing creates a more structurally and floristically diverse sward that also benefits other invertebrates (Carvell, 2002).	20. Management of Coastal and Lowland Heath / 20B. Management of Coastal and Lowland Heath With Mixed Grazing Option 148 Coastal grassland (maritime cliff and slope)	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • <u>></u> 25% dwarf-shrub species on coastal heath • <u><</u>25% of heath burnt over 5 years • Sheep/cattle grazing on coastal grassland • <u>Presence of coastal heath and grassland</u> • <u>High species richness</u> • <u>Cattle grazing</u>	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping Habitat mapping Habitat mapping X, Y & U plots Habitat mapping

The loss of unimproved grasslands coupled with the narrow diet of carder bees compared to the common bee species is thought to be one of main causes of carder bee decline (Goulson, 2010). *B. sylvarum* and *B. humilis* utilise a network of forage sources over site- and landscape-scales therefore conservation of a single site might not be sufficient to support populations. A network of forage and nesting habitat at a site- and landscape-scale is required to support viable metapopulations and to buffer colonies against the effects of forage patch losses (Connop et al. 2011). *B.humilis* need areas of large, fairly tall, open grasslands with small, but widely distributed patches of long-tubed flowers preferred for foraging (Carvell, 2002; buglife, n.d). Study by Carvell (2002) showed that *B .humilis* numbers were significantly related to increased vegetation structure, height and total flower abundance. The bumblebee working group (2002) also consider that foraging habitat is dependent upon the structure of the grassland (i.e mosaic of vegetation structure, tall and open) as much as the exact composition of the flora. However numerous studies have observed that there is obvious preference towards some plant species. Flower families most favoured and visited by *B. humilis* include Lamiaceae, Scrophulariaceae, Asteraceae and particularly Fabaceae (Connop, 2010; Connop, 2008; Carvell, 2002; Buglife n.d). *B. humilis* emerge late from hibernation in comparison to other bees, as such workers require relatively late forage (Goulson, 2010) and have been recorded foraging in late September and even into early October in this study (Connop 2008). As such it is vital that sites	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture) 128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture) 131 Conversion from arable to grassland (no inputs) 133 Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture)	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep • Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm • Area of new grassland • Grassland grazed once established • Sward height at least 5cm • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping, X plot Habitat mapping Habitat mapping, X, U & Y plots

have a continuum of flowers from late May to late September (Saunders 2008; Bumblebee Conservation Trust, n.d (a)). Buglife (n.d) suggests that stands of flowering knapweed, burdock and thistle should be protected as these provide food for foraging Queens. Grazing plays a key role in maintaining the abundance and species richness preferred bumblebee forage plants such as C. nigra and T. pratense. Recently sheep and cattle grazed grassland found to support B. humilis. Cattle are particularly suitable for bee conservation as their grazing creates a more structurally and floristically diverse sward than grazing by sheep; this also benefits other invertebrates (Carvell, 2002). The importance of undisturbed grassland becomes particularly clear with the understanding of nesting preferences. Generally they nest on the surface of the ground (surface nesting species) at the base of long vegetation, often under accumulated dried plant litter or moss at the base of the vegetation. Sunlight provides warmth to the surface of the nests, but they are also known to utilise old nests of small mammals (Hymettus, 2002; Natural Museum & Galleries of Wales, n.d).		• High % of Scrophulariaceae, Orobanchaceae, Asteraceae, Lamiaceae and particularly Fabaceae flowering plants in grassland • Tall vegetation • Stands of knapweed, burdock & thistles • Litter • Bryophytes • Tussocky vegetation • Mosaic of unimproved flower rich grassland	X, Y or U plots Habitat mapping; X, Y or U plots Habitat mapping X, Y or U plots X, Y or U plots X, Y or U plots Habitat mapping
Carder bees are reliant on tall, undisturbed grassland, particularly tussocky grassland (Connop 2008). Sowing non-crop field margins with wildlife seed mixtures has the potential for providing the best foraging habitat for bumblebees through the season, so long as preferred forage species are introduced such *as Trifolium pratense, Lotus corniculatus* and *Centaurea nigra* (Goulson 2010; Carvell et al. 2006; Pwyll, 2005).	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping

Glastir prescriptions suggest a tussock-forming grass mixture should be sown. In support of this, a study by Carvell (2004) created 6m wide arable field margin sown with 'tussocky grasses'. After three years, (having being left uncut after year one), the margin had developed into the expected tussocky structure thought to be ideal for nest seeking queen's. Most favoured plant families include Fabaceae, Lamiaceae, Asteraceae and Scrophulariaceae (Bug life n.d). Study in Salisbury plain mostly recorded *B. humilis* within the taller less intensively managed, reverting arable grasslands due to their structural suitability as nesting habitat, as well as the availability of forage plants (Carvell, 2002). The importance of undisturbed grassland becomes particularly clear with the understanding of nesting preferences. Generally carder bees nest on the surface of the ground at the base of long, tussocky vegetation, often under accumulated dried plant litter or moss at the base of the vegetation. Sunlight provides warmth to the surface of the nests, but they are also known to utilise old nests of small mammals such as voles (Bumblebee Working Group, 2002; Natural Museum & Galleries of Wales, n.d.)	27 Fallow margins 174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated • New fallow crop margin adjacent to cereals, oil seed rape, linseed, maize or roots • Between 2-8m wide • Can be rotated • New rough grass margin on arable land • Livestock excluded • <u>Tussocky vegetation</u> • <u>High % of Scrophulariaceae, Orobanchaceae, Asteraceae, Lamiaceae and particularly Fabaceae flowering plants in grassland</u> • <u>% litter</u> • <u>% bryophytes</u>	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping
Carder bees are reliant on tall, undisturbed grassland, particularly tussocky grassland (Connop 2008) as well as smaller patches that are widely distributed. A study by Carvell (2002) also showed that *B .humilis* numbers were significantly related to increased vegetation structure, height and total flower abundance.	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub 175 - Management of rough grassland; enclosed land	• New area of rough grassland in field corner (Max size 0.35ha) • New length and location of stock proof • No/Minimal scrub on rough grs (enclosed land) • Varied sward height >20cm	Habitat mapping Linears and fence condition Habitat mapping Habitat mapping

		• Tussocky grassland • Tall vegetation	
Habitats peripheral to the cliffs are also important, such as dunes (Saunders, 2008). In the past, national records have found the remaining populations of *B humilis* & *B.sylvarum* have a coastal distribution (Connop 2008; Buglife, n.d).	25 Management of sand dunes 25B Management of sand dunes with mixed grazing 151 Coastal vegetated shingle and sand dunes - creation	• Grazing by cattle, sheep, goats or ponies • Managed by grazing • At least 20% <5cm and at least 40% <10cm • Grass cover <70% in wet hollows	Habitat mapping
B. humilis emerge late from hibernation in comparison to other bees, as such workers require relatively late forage (Goulson, 2010). Carvell (2000) and bumblebee conservation trust (n.d) recommend cutting should be delayed until mid-July to August or if a farm has numerous hay meadows then a field (rotating each year) should be late in September. A later cut therefore maintains forage flowers into late season. Hay cutting prescriptions recommend that hay is cut after 8th July. No other specification for cutting, as such this may detrimental for bees.	22 Existing haymeadows 122 Lowland unimproved acid grassland - reversion (hay cutting) / 124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting) / 130 Lowland unimproved calcareous grassland - reversion (hay cutting) / 132 Conversion from improved grassland to semi- improved grassland (hay cutting) 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high • Grassland maintained by grazing and hay cutting • Field shut off from livestock by 1 May every year • Between 5-10% left uncut • Aftermath sward height - 80% of the grasses between 5- 15cm high • Change from improve grassland to semi-improved grassland • Grassland maintained by grazing and hay cutting • Between 5-10% left uncut	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plots Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plots

		• Aftermath sward height - 80% of the grasses between 5- 15cm high	
Unable to find evidence; however Claire Carvell (pers comm.) suggest these measures have the potential to provide forage resources depending on seedbank.	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing	• Sward height (excluding rushes) between 5-30cm on enclosed land • Sheep & Cattle grazing on marshy grs (enclosed land) • Sward height (excluding rushes) between 5-30cm on enclosed land • Presence of marshy grassland	Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping, X, Y & u plots Habitat mapping
Unable to find evidence; however Claire Carvell (pers comm.) suggest these measures have the potential to provide forage resources depending on cover crop chosen i.e. nectar/pollen rich.	33 Establish a wildlife cover crop on improved land 34 Unharvested cereal headland 34B Unfertilised and unsprayed cereal headland	• On improved land only • 4m wide seed bed established for crop • Crop cover to be at least 80% cereals with at least one of the following; mustard, rape or linseed. • No maize • Only on improved land • 3-6m wide cereal headland established along edge of crop • Only on improved land • 3-6m wide cereal headland established along edge of crop Can be rotated	Habitat mapping Habitat mapping M plot M plot Habitat mapping Habitat mapping Habitat mapping Habitat mapping
Unable to find evidence	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping Habitat mapping

Unable to find evidence	115 Lowland dry heath with less than 50% western gorse / 116 Lowland dry heath with more than 50% western gorse 117 Lowland wet heath with less than 60% purple moor- grass / 118 Lowland wet heath with more than 60% purple moor-grass 119 Lowland heath habitat expansion - establishment on grassland	Minimal guidance	

SHRILL CARDER BEE – *Bombus sylvarum*

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Bombus sylvarum one of the longer-tongued bumblebee species that emerges relatively late in the season, in May (Bumblebee Conservation Trust, n.d (b)). Providing hedges are not intensively managed or degraded by herbicides, uncropped areas of farmland such as hedgerows may provide flowers throughout the season for foraging bumblebees. (Goulson, 2010). Carvell et al (2006) also suggest that sympathetic management of vegetation along hedgerows edges could also encourage plants such as *Ajuga reptans* and *Lamium album*, both of which provide spring forage. Hymettus (2002) similarly recognised that hedge-bottom plants such as labiates in less intensive agricultural situations were important forage components for long-tongue bumblebee species.	1/1B Create a 3m or 2m corridor to include tree and shrub planting on improved land	• New WLF on improved land • WLF to grow at least 2m wide • New stock proof, double fence • Species richness; $\geq$ 5 woody species • Rough grass margin between hedge and fence • Hedgerow saplings/trees at intervals of 20-70m	Habitat Mapping –linears Habitat mapping; B & D plots Linears & Fence condition B & D plots Habitat mapping – linears B & D plots
	2/2B Create a 3m or 2m corridor to include earth bank and tree and shrub planting on improved land	• New earth bank at least 0.75m high and 0.75m wide • WLF to grow at least 2m wide • New stock proof, double fence • New rough grass margin between fence and WLF • Species richness; $\geq$ 5 woody species • Up to 75% of plants may be hawthorn and/or blackthron	Habitat mapping – linears Habitat mapping; B & D plots Linears & Fence condition Habitat mapping – linears B & D plots B & D plots
	3 Create a wildlife corridor – established woody strip	• New WLF on improved land • WLF between 5-15m wide • New stock proof fencing • Species richness ; $\geq$ 5 woody species • $\leq$ 25% native conifers	Habitat mapping - linears Linears & Fence condition B & D plots B & D plots B & D plots

	6 Double fence gappy hedges / 6B Double fence gappy hedgerows at a 2 metre width (1 metre from centre) / 42A Hedgerow Restoration With Fencing	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF maintained at least 1.5m high and 1.5m wide • Hedgerow saplings/trees at intervals of 20-70m	Linears & Fence condition Habitat mapping - Linears B & D plots Habitat mapping; B & D plots B & D plots
	42B. Hedgerow restoration without fencing	• Hedgerow trees at intervals of 20-70m • Decrease in vertical gappiness	D plots D plots
	43A/43B. Double Fence and Restore Hedge Banks With/without Planting	• New stock proof, double fencing around existing hedges • New margin between hedge and fence • Decrease in vertical gappiness • WLF restored to a minimum of 0.5m high and 0.5m wide • Hedgerow saplings/trees at intervals of 20-70m • <u>Presence of Labiates in hedgerows</u> • <u>Connectivity to flower rich grassland</u>	Linears & Fence condition Habitat mapping - Linears Habitat mapping - Linears Habitat mapping; B & D plots B & D plots
One of the major agricultural changes in Britain is the loss of red clover leys (Goulson, 2010), yet red clover is one of the most important food plants of *B.humilis* & B. *sylvarum* (Hymettus, 2006; Bug life n.d). It has also been found that the Fabaceae family is disproportionally favoured as forage plants (Goulson, 2010; Connop, 2007; Saunders, 2008). Knowing this, the creation of red clover leys theredore has the potential to encourage the expansion of this	153 - Red clover ley	• Area of new red clover ley • $\geq$ 80% of sward is red clover	Habitat mapping, X plot

species, particularly as red clover often flowers late into the summer (Bumblebee conservation trust, n.d).			
Recent national records have found the remaining populations of *B humilis* & *B.sylvarum* have a coastal distribution (Connop 2008; Buglife, n.d.a). Grazing plays a key role in maintaining the abundance and species richness preferred bumblebee forage plants. Cattle are particularly suitable for bee conservation as their grazing creates a more structurally and floristically diverse sward that also benefits other invertebrates (Carvell, 2002).	20. Management of Coastal and Lowland Heath 20B. Management of Coastal and Lowland Heath With Mixed Grazing Option 148 - Coastal grassland (maritime cliff and slope)	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • <u>></u> 25% dwarf-shrub species on coastal heath • <u><</u>25% of heath burnt over 5 years • Sheep/cattle grazing on coastal grassland • <u>High species diversity</u> • <u>Cattle grazing</u>	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping Habitat mapping
The loss of unimproved grasslands coupled with the narrow diet of carder bees compared to the common bee species is thought to be one of main causes of carder bee decline (Goulson, 2010). *B. sylvarum* and *B. humilis* utilise a network of forage sources over site- and landscape-scales therefore conservation of a single site might not be sufficient to support populations. A network of forage and nesting habitat at a site- and landscape-scale is required to support viable metapopulations and to buffer colonies against the effects of forage patch losses (Connop et al. 2011). Shrill carder bee needs large, continuous patches of flowering plants (buglife, n.d). Flower families preferred by *B.sylvarum* workers include Lamiaceae, Orobanchaceae, Scrophulariaceae and Fabaceae, all of which are visited roughly equally (Connop, 2008; Buglife n.d). Connop (2008) found B.sylvarum preferred to forage on Odontites verna and points out this plant has been consistently recorded as a favourite forage plant in other previous studies including Edwards(1999), Harvey (1999);	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture)	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots

and Harvey (2000). In a separate study, the Hymettus (2002) also identified a strong association with Odontites verna. However the bumblebee working group (2002) felt that foraging habitat was dependent upon the structure of the grassland (tall and open) as much as the exact composition of the flora, although it was obvious that some plants were favoured. Also been suggested that density of suitable flower resources seems to be the decisive factor (Hymettus, 2006). Horsley et al (2013) suggest that management should be to maintain large expanses of unimproved, flower-rich habitat using traditional management i.e. grazing or cutting. Bug life (n.d) suggests that stands of flowering knapweed, burdock and thistle should be protected to provide food for foraging Queens. Grazing plays a key role in maintaining the abundance and species richness preferred bumblebee forage plants such as C. nigra and T. pratense. Cattle are particularly suitable for bee conservation as their grazing creates a more structurally and floristically diverse sward that also benefits other invertebrates (Carvell, 2002). B. humilis and B. sylvarum emerge late from hibernation in comparison to other bees, as such workers require relatively late forage (Harvey, 2000) and have been recorded foraging in late September and even into early October in this study (Connop 2008). As such it is vital that sites have a continuum of flowers stretching from late May to late September (Saunders 2008; Bumblebee conservation trust, n.d).	128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture) 131 Conversion from arable to grassland (no inputs) 133 Lowland marshy grassland / 134 Lowland marshy grassland; reversion (pasture) .	• Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm • Area of new grassland • Grassland grazed once established • Sward height at least 5cm • Grazing of Marshy grassland • Varied sward – 80% of grasses (excluding rushes) between 10 & 30cm • High % of Scrophulariaceae, Orobanchaceae, Asteraceae, Lamiaceae and particularly Fabaceae flowering plants in grassland • Presence of *Odontites verna* • Tall vegetation • Stands of knapweed, burdock & thistles • Litter • Bryophytes • Tussocky vegetation • Large expanse of unimproved flower rich grassland • Cattle grazing	Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping, X plot Habitat mapping Habitat mapping, X, U & Y plots X, Y or U plots X, Y or U plots Habitat mapping; X, Y or U plots Habitat mapping X, Y or U plots X, Y or U plots X, Y or U plots Habitat mapping Habitat mapping
Carder bees are reliant on tall, undisturbed grassland, particularly tussocky grassland (Connop 2008). Sowing non-crop field margins with wildlife seed mixtures has the potential for providing the best foraging habitat for	26 Fixed rough grass margins on arable land	• New rough grass margin • Width of 2-8m on arable land • No grazing once established	Habitat mapping Habitat mapping Habitat mapping

bumblebees through the season, so long as preferred forage species are introduced such as Trifolium pratense, Lotus corniculatus and Centaurea nigra (Goulson 2010; Carvell et al. 2006; Pwyll, 2005). Glastir prescriptions suggest a tussock-forming grass mixture should be sown. In support of this, a study by Carvell (2004) created 6m wide arable field margin sown with 'tussocky grasses'. After three years, (having being left uncut after year one), the margin had developed into the expected tussocky structure thought to be ideal for nest seeking queen's. Most favoured plant families include Fabaceae, Lamiaceae, Asteraceae and Scrophulariaceae (Bug life n.d). Study in Salisbury plain mostly recorded B. humilis within the taller less intensively managed, reverting arable grasslands due to their structural suitability as nesting habitat, as well as the availability of forage plants (Carvell, 2002). The importance of undisturbed grassland becomes particularly clear with the understanding of nesting preferences. Generally carder bees nest on the surface of the ground at the base of long, tussocky vegetation, often under accumulated dried plant litter or moss at the base of the vegetation. Sunlight provides warmth to the surface of the nests, but they are also known to utilise old nests of small mammals such as voles (Hymettus, 2002; Natural Museum & Galleries of Wales, n.d.) Management recommendations from Horsley et al (2013) include retained isolated patches of coarse vegetation to provide nesting opportunities for the species.	26B Rotational rough grass margin on arable land 27 Fallow margins 174 Rough grass buffer zone to prevent erosion and run-off from land under arable cropping	• Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated • New fallow crop margin adjacent to cereals, oil seed rape, linseed, maize or roots • Between 2-8m wide • Can be rotated • New rough grass margin on arable land • Livestock excluded • Tussocky vegetation • High % of Scrophulariaceae, Orobanchaceae, Asteraceae, Lamiaceae and particularly Fabaceae flowering plants in grassland • % litter • % bryophytes	Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping
Carder bees are reliant on tall, undisturbed grassland, particularly tussocky grassland (Connop 2008) as well as smaller patches that are widely distributed. A study by Carvell (2002) also showed that B .humilis numbers were significantly related to increased vegetation structure, height and total flower abundance. Generally	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub	• New area of rough grassland in field corner (Max size 0.35ha) • New length and location of stock proof	Habitat mapping Linears and fence condition

carder bees nest on the surface of the ground at the base of long, tussocky vegetation, often under accumulated dried plant litter or moss at the base of the vegetation. Sunlight provides warmth to the surface of the nests, but they are also known to utilise old nests of small mammals such as voles (Hymettus, 2002; Natural Museum & Galleries of Wales). Management recommendations from Horsley et al (2013) include retaining isolated patches of coarse vegetation to provide nesting opportunities for the species.	175 - Management of rough grassland; enclosed land	• No/Minimal scrub on rough grs (enclosed land) • Varied sward height >20cm • <u>Tussocky grassland</u> • <u>Tall vegetation</u>	Habitat mapping Habitat mapping
Habitats peripheral to the cliffs are also important, such as dunes (Saunders, 2008). In the past, national records have found the remaining populations of *B humilis* & *B.sylvarum* have a coastal distribution (Connop 2008; Buglife, n.d).	25 Management of sand dunes 25B Management of sand dunes with mixed grazing 151 Coastal vegetated shingle and sand dunes - creation	• Grazing by cattle, sheep, goats or ponies • Managed by grazing • At least 20% <5cm and at least 40% <10cm • Grass cover <70% in wet hollows	Habitat mapping
B. humilis and B. sylvarum emerge late from hibernation in comparison to other bees, as such workers require relatively late forage (Goulson, 2010). Carvell (2000) and bumblebee conservation trust (n.d) recommend cutting should be delayed until mid-July to August or if a farm has numerous hay meadows then a field (rotating each year) should be late in September. A later cut therefore maintains forage flowers into late season. Hay cutting prescriptions recommend that hay is cut after 8th July. No other specification for cutting, as such this may detrimental for bees.	22 Existing haymeadows 122 Lowland unimproved acid grassland - reversion (hay cutting) / 124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion (hay cutting) / 130 Lowland unimproved calcareous grassland - reversion (hay cutting) / 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high • Grassland maintained by grazing and hay cutting • Field shut off from livestock by 1 May every year • Between 5-10% left uncut • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plots

	132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Change from improve grassland to semi-improved grassland • Grassland maintained by grazing and hay cutting • Between 5-10% left uncut • Aftermath sward height - 80% of the grasses between 5- 15cm high	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plots
Unable to find evidence; however Claire Carvell (pers comm.) suggest these measures have the potential to provide forage resources depending on seedbank.	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing	• Sward height (excluding rushes) between 5-30cm on enclosed land • Sheep & Cattle grazing on marshy grs (enclosed land) • Sward height (excluding rushes) between 5-30cm on enclosed land • Presence of marshy grassland	Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping, X, Y & u plots Habitat mapping
Unable to find evidence; however Claire Carvell (pers comm.) suggest these measures have the potential to provide forage resources depending on cover crop chosen i.e. nectar/pollen rich.	33 Establish a wildlife cover crop on improved land 34 Unharvested cereal headland 34B Unfertilised and unsprayed cereal headland	• On improved land only • 4m wide seed bed established for crop • Crop cover to be at least 80% cereals with at least one of the following; mustard, rape or linseed. • No maize • Only on improved land • 3-6m wide cereal headland established along edge of crop • Only on improved land • 3-6m wide cereal headland established along edge of crop Can be rotated	Habitat mapping Habitat mapping M plot M plot Habitat mapping Habitat mapping Habitat mapping Habitat mapping

No evidence	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping Habitat mapping
Unable to find evidence	115 Lowland dry heath with less than 50% western gorse / 116 Lowland dry heath with more than 50% western gorse 117 Lowland wet heath with less than 60% purple moor- grass / 118 Lowland wet heath with more than 60% purple moor-grass 119 Lowland heath habitat expansion - establishment on grassland	Minimal guidance	

HIGH BROWN FRITILLARY

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Grass/bracken mosaics below 300m, situated on south-facing slopes are most likely to support high brown fritillaries. Breeding areas are characterised by short sparse vegetation with little grass cover as well as violets growing through a shallow layer of bracken litter (<15cm). Females lay their eggs individually on the leaves and stems of dead bracken. Once the caterpillars emerge, long periods of time are spent basking on bracken litter. Time is also spent feeding on the leaves of Common Dog-violet (Bulman et al, 2005; Ellis et al, 2012). Extensive grazing by cattle and ponies is ideal to create/maintain ideal habitats for this species is they help to break up the dense trash, thus opening up the canopy for violets (Warren & Wigglesworth, n.d (a)). * As detailed by Barnett & Warren (1995), adults will feed on; Bramble (*Rubus fruticosus*) blossom Common Knapweed (*Centaurea nigra*) Thistle species (*Cirsium* spp.) Ragwort (*Senecio jacobaea*) Betony (*Stachys officinalis*) Field scabious (*Knautia arvensis*) And hawkbits	15 Grazed permanent pasture with no inputs. / 15C Grazed permanent pasture with no inputs and mixed grazing Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture) 128 Lowland unimproved calcareous grassland / 129 Lowland unimproved calcareous grassland - reversion (pasture) 122 Lowland unimproved acid grassland - reversion (hay cutting) / 124 Lowland unimproved neutral grassland – haymeadow / 126 Lowland unimproved neutral grassland - reversion	• Permanent pasture maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep • Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm • Grassland maintained by grazing and hay cutting • Field shut off from livestock by 1 May every year • Between 5%-10% left uncut	Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping Habitat mapping

	(hay cutting) / 130 Lowland unimproved calcareous grassland - reversion (hay cutting) / 132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Aftermath sward height - 80% of the grasses between 5- 15cm high • Bracken stands or grass/bracken mosaics on south facing slopes (below 300m) • Grazing by cattle or ponies • Presence of * species	Habitat mapping; X & Y plots Habitat mapping, X & U plots Habitat mapping Habitat mapping' X & Y plots
Grass/bracken mosaics below 300m, situated on south-facing slopes are most likely to support fritillaries. Breeding areas are characterised by short sparse vegetation with little grass cover as well as violets growing through a shallow layer of bracken litter (<15cm). Females lay their eggs individually on the leaves and stems of dead bracken. Once the caterpillars emerge, long periods of time are spent basking on bracken litter. Time is also spent feeding on the leaves of Common Dog-violet (Bulman et al, 2005; Ellis et al. 2012). Feeding also occasionally occurs on Hairy Violet (*Viola hirta*), Heath Dog-violet (*Viola canina*) and Pale Dog-violet (*Viola lactea*) (Warren & Barnett, 1995). Extensive grazing by cattle and ponies is ideal to create/maintain ideal habitats for this species is they help to break up the dense trash, thus opening up the canopy for violets (Warren & Wigglesworth, n.d). Breeding requirements of the high brown fritillary defined by Warren & Key (1991) and Warren (1992). • Dense bracken stand with a canopy between 30-70% cover •Bracken height between 40-110cm	44 Mechanical bracken control	• Areas of Bracken • Change in bracken height • Bracken stands or grass/bracken mosaics on south facing slopes (below 300m) • Bracken height between 40 - 110cm • Bracken Litter • Short vegetation growing through bracken litter • 10-25% cover of Common-Dog violet in bracken understory • <30% grass cover • Grazing by cattle or ponies	Habitat mapping Habitat mapping Habitat mapping, U plots Habitat mapping, U plot U plots U plots Habitat mapping, U plots Habitat mapping, U plots Habitat mapping

•The larval food plant, common dog violet is abundant (10- 25% cover) amongst a sparse ground vegetation under bracken • Bracken litter 5-l0cm with low grass cover 30%) and low levels of bracken "thatch" (accumulation of dead bracken litter in the sub-canopy) •Sites are on sheltered, south-facing below 300m altitude Stands of bracken on uplands are moorlands are unsuitable because they are too acidic and do not contain violets (Warren & Wigglesworth, n.d).			
(CRoW Act definition of 'open country' – mountain, moor, heath and downland). Extensive grazing by cattle and ponies is ideal to create/maintain ideal habitats for this species is they help to break up the dense trash, thus opening up the canopy for violets (Warren & Wigglesworth, n.d (a)).	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country' • <u>Grazing by cattle and ponies</u>	Habitat mapping Habitat mapping Habitat mapping
As detailed by Barnett & Warren (1995), adults will feed on Bramble (*Rubus fruticosus*) blossom.	103 Scrub - stock exclusion	• Existing area of scrub • New stock proof fencing around areas of scrub • <u>Areas of bramble</u>	Habitat mapping Linears and fence condition

MARSH FRITILLARY

Evidence obtained from Literature	**Target Species and Glastir Measures**	**Specific Response Variables**	**GMEP Survey Data That Captures Measure or Target**
Devil's bit scabious (*Succisa pratensis*) is the larval food plant of the marsh fritillary. When egg-laying, females lay their eggs on the underside of the plant's leaves and have a tenancy to choose the largest leaves for this purpose; field scabious and small scabious are also occasionally used (Gaywood, n.d; Warren & Wigglesworth, n.d (b)). Devil's bit scabious leaves used for egg laying are typically found in swards of 8-25cm, or shorter swards of 5-15cm when the food plant is abundant. (Warren & Wigglesworth, n.d (b)). Damp, acid or healthy grassland, where devil's-bit scabious is abundant, is one of the two main types of habitat which support marsh fritillary. These habitats are normally open, unshaded and dominated by tussock-forming grass such as *Molinea caerulea* on more acidic soils or *Deschampsia caespitosa* on more neutral soils (Warren, 1994; Butterfly Conservation, n.d). Dry, calcareous grassland is the second of the two major habitats, but this is predominately found in central, southern Britain, usually on west or south facing slopes (Warren, 1994). In Wales, marsh fritillaries will also breed in unimproved neutral grassland (Fowles & Smith, 2006). The marsh fritillary exhibits metapopulation dynamics as there is regular turnover of colonies causing high rates of extinction but also some colonisation of new sites due to their ability to dispersal. Since colonies are interconnected, the long term survival of the species is	19 Lowland marshy grassland 19B Management of lowland marshy grassland with mixed grazing 123. Lowland unimproved neutral grassland – pasture 133. Lowland marshy grassland 134. Lowland marshy grassland; reversion (pasture) 117 Lowland wet heath with less than 60% purple moor- grass 118 Lowland wet heath with more than 60% purple moor-grass 139 Lowland bog and other acid mires with less than 50% purple moor-grass 140 Lowland bog and other acid mires with more than 50% purple moor-grass	• Sward height (excluding rushes) between 5-30cm on enclosed land • Mixed grazing • Sward height (excluding rushes) between 5-30cm on enclosed land • Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm – 20cm • Sward height between 5cm – 20cm when not grazed by sheep • Grazing of Marshy grassland • Sward height between 10cm-30cm • Area of lowland wet heath with <60% purple moor-grass • Area of lowland wet heath with >60% purple moor-grass • Area of lowland bog/acid mire with <50% purple moor-grass	Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping, X, Y & u plots Habitat mapping Habitat mapping Habitat mapping

dependent on the protection of a mosaic of suitable, large habitat patches in close proximity. This therefore allows successful dispersal at times of high population levels, but also compensates for the periodic local extinctions to which local populations are prone (Warren 1994). A study by Schtickzelle et al. (2005) suggests the restoration or enlargement of existing habitat patches, as well as the creation of new habitat patches will help to improve metapopulation viability and the larger the habitat area, the better. Ideally, scrub more than 0.5 m tall) should covers no more than 5% of area (Fowles, 2003). Populations can fluctuate from year to year due to food supply, bad weather and caterpillar parasitism by *Cotesia melitaearum* and *Cotesia bignellii* (Barnett & Warren, 1995; Gaywood, n.d). Bulman (2001) studied parasitoid attack and found that *Cotesia bignelli* appears to have metapopulation dynamics. The presence of parasitoids may therefore be a major cause of variation and metapopulation dynamics of the marsh fritillary, and may help to explain the butterfly's requirement of large habitat patches.	141 Lowland bog and other acid mires - restoration (no grazing)	• Area of lowland bog/acid mire with <50% purple moor-grass • Area of lowland bog/acid mire • High % of *Succisa pratensis* • Tussocky sward • Sward height 12-25cm • Cattle or horse grazing only • Presence of *Cotesia melitaearum* and *Cotesia bignelli* (parasitic wasps) • Scrub >0.5m tall covers <5% area within habitat patches • Species rich • Closely connected, large habitat patches together exceeding 2ha*	Habitat mapping Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping Habitat mapping Habitat mapping, Invertebrate survey Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	20. Management of Coastal and Lowland Heath / 20B. Management of Coastal and Lowland Heath With Mixed Grazing	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • ≥ 25% dwarf-shrub species on coastal heath • ≤25% of heath burnt over 5 years	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	Option 143 - Lowland fen 145 - Lowland fen; reversion (pasture) 144 Lowland fen - restoration (no grazing)	• Grazing on Lowland fen • Sward height between 10cm-80cm (except patches of moss) • Area of restored/new lowland fen	Habitat mapping Habitat mapping, X & U plots Habitat mapping

Unable to find evidence	400 Additional Management Payment - Stock management 403 Additional Management Payment Re-wetting	Minimal guidance, additional payment.	

PEARL BORDEDED FRITILLARY

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
To the west of Britain, the main breeding habitat of the pearl bordered fritillary is rough grassland, hillside bracken stands with violets growing through a shallow (<15cm) layer of bracken litter and/ or scattered scrub, often gorse and blackthorn (Barnett & Warren, 1995b; Warren & Wiggleworth n.d). The key larval food-plant throughout its range is Common Dog-Violet (*Viola riviniana*) but further north Marsh Violet (*V. palustris*) can be used, and other species such as Heath Dog-Violet *Viola canina* may be used in some habitats. A mosaic of bracken and grassy patches as well as abundant violets growing through the bracken litter is an ideally suited habitat. The mosaic is typically 1/3 grass to 2/3 bracken. To create this type of habitat, extensive grazing by cattle and ponies is ideal, particularly as trampling by animals helps to break up the bracken trash and opens up the bracken canopy to provide germination sites for violets (Warren & Wigglesworth, n.d (c)). Adults feed in areas where there are plenty of spring flowers, like bugle and thistle (Barnett & Warren, 1995; Warren & Wigglesworth, n.d (c)). Sheep are the least appropriate grazing animal as they do not trample bracken beds sufficiently, and may also eliminate nectar plants (Brereton, n.d).	Option 120 - Lowland unimproved acid grassland / 121. Lowland unimproved acid grassland - reversion (pasture)	• Grassland maintained by grazing • Varied sward - 20% of grasses >7cm and 20% of grasses <7cm • Grassland maintained by grazing • At least 75% of grasses and herbs between 3cm-20cm	Habitat mapping Habitat mapping; X & U plots Habitat mapping Habitat mapping; X & U plots
	123. Lowland unimproved neutral grassland – pasture / 125. Lowland unimproved neutral grassland - reversion (pasture)	• Sheep grazing on unimproved neutral grs • Sheep & Cattle grazing on unimproved neutral grs • Sward height between 10cm & 20cm • Sward height between 5cm & 20cm when not grazed by sheep	Habitat mapping Habitat mapping Habitat mapping; X & Y plots Habitat mapping; X & Y plots
	128 Lowland unimproved calcareous grassland	• Grassland maintained by grazing • Varied sward – at least 75% of grasses and herbs between 3cm & 50cm	Habitat mapping Habitat mapping; X & U plots
	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country'	Habitat mapping Habitat mapping

		• Hillside bracken stands on rough grassland • Violets growing through bracken litter • Grassland mosaic (30% grass to 60% bracken) • Scattered scrub particularly gorse and blackthorn on grassland • Grazing by cattle and ponies • Presence of spring flowers i.e. Bugle & thistle	
To the west of Britain, the main breeding habitat of the pearl bordered fritillary is rough grassland, hillside bracken stands with violets growing through a shallow (<15cm) layer of bracken litter and/ or scattered scrub, often gorse and blackthorn (Barnett & Warren, 1995; Warren & Wiggleworth n.d). The female butterflies lay their eggs singly on dead bracken litter near to violets and once hatched, the caterpillars feed intermittently on common dog violet, particularly the young leaves which grow through the shallow stands of bracken litter. (Bulman et al. 2005; Brereton, n.d; Warren & Barnett, 1995; Warren & Wigglesworth, n.d (c)). Cutting should not be seen a replacement for grazing. If cutting is the only option, areas of Bracken (0.5 to 1ha) should be cut during late May or early June over a 3 to 10 year period (Bulman et al. 2005).	44 Mechanical bracken control	• Cutting between 1st May & 15th August • Hillside bracken stands on rough grassland • Violets growing through bracken litter • Grazing by cattle and ponies	Habitat mapping Habitat mapping Habitat mapping, U plots Habitat mappin
To the west of Britain, the main breeding habitat of the pearl bordered fritillary is rough grassland, hillside bracken stands with violets growing through a shallow (<15cm) layer of bracken litter and/ or scattered scrub (Barnett & Warren, 1995; Warren & Wiggleworth n.d).	103 Scrub - stock exclusion	• Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition Habitat mapping

As well as bracken litter, other leaf litter, (including bramble) is important because it provides a place for the caterpillars to hibernate during the winter months (Bulman et al, 2005; Warren & Barnett, 1995).		• Scattered scrub in grassland • Presence of leaf litter	Unlikely to be recorded
Extensive grazing by cattle and ponies is ideal, particularly as trampling by animals helps to break up the bracken trash and opens up the bracken canopy to provide germination sites for violets (Warren & Wigglesworth, n.d (c)).	400 Additional Management Payment - Stock management 401 Additional Management Payment - Mixed grazing 411 Additional Management Payment - Reduce stocking	Minimal guidance	Unlikely to be measured
Unable to find evidence	20. Management of Coastal and Lowland Heath 20B. Management of Coastal and Lowland Heath With Mixed Grazing	• Grazing by cattle, sheep, goats or ponies • >50% dwarf shrub species on lowland heath • ≥ 25% dwarf-shrub species on coastal heath • ≤25% of heath burnt over 5 years	Habitat mapping Habitat mapping, X, Y & U plots Habitat mapping, X, Y & U plots Habitat mapping
Unable to find evidence	148 Coastal grassland (maritime cliff and slope)	• Sheep/cattle grazing on coastal grassland	Habitat mapping
Unable to find evidence	15 Grazed permanent pasture with no inputs. 15C Grazed permanent pasture with no inputs and mixed grazing	• Permanent pasture maintained • Grazing/ Mixed grazing	Habitat mapping Habitat mapping

WELSH CLEARWING

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Welsh Clearwing females lay their eggs in the bark crevices of mature, often isolated/scattered birch trees, over 40-50 years old, in open situations with sunlit trunks. Both Silver Birch Betula pendula and Downy Birch Betula pubescens are used. The caterpillars feed and grow within the inner bark of the trees for up to 2-3 years until pupation takes place (Butterfly Conservation Wales, n.d; Knowler, n.d). If the trees are not currently used by the moth, it is advised that all existing, old birch trees should be retained, as these may be colonised in future (Butterfly Conservation Wales). A study in England and Wales using known records of the species found almost 60% of the pupae emergent holes occur at high altitude on the warmer South side of the host tree (Bevan & Forman, 2013). Very little is known the ecology of the Welsh clearwing other than the preference for rearing larva in the trunks of Birches. Furthermore, there is little known reason why the species is not more wide spread in Wales (Bevan & Forman, 2013).	13 Plant individual native trees on improved land 104 Wood pasture	• New individual broadleaved native trees on improved land • Tree guards or fencing around new trees • No new ash trees • Area of wood pasture • Grazed grass understory • <u>Presence of existing, mature Silver and/or downy birch trees</u> • <u>Scattered or isolated birch trees</u>	Habitat mapping – Points Habitat mapping – Points Habitat mapping – Points Habitat mapping Habitat mapping Habitat mapping – Points Habitat mapping - Points

"In even aged stands, where trees could die at the same time, ensure the establishment of new trees to provide continually maturing trees for the future" (Butterfly Conservation Wales, n.d).	101. Trees and scrub - establishment by Planting 102. Trees and scrub - establishment by natural regeneration	• New area of trees and scrub • New length of stock proof fence	Habitat mapping Linears and fence condition assessment
	103 Scrub - stock exclusion	• Existing area of scrub • New stock proof fencing around areas of scrub	Habitat mapping Linears and fence condition assessment

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BLACK GROUSE

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
(CRoW Act definition of 'open country' – mountain, moor, heath and downland)	41A Grazing management of open country	• Grazing of 'open country'	Habitat mapping
Black grouse require a mosaic of upland habitats because they are depend on different type of vegetation to support their yearly lifecycle (RSPB, n,d. (a)).	41B Grazing management of open country with mixed grazing	• Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping
	16 Upland heath	No guidance	
A study in Wales (Cayford, 1990) and studies in the Northern Pennines (Baines, 1994; Starling-Westeberg, 2001) have all found heather and bilberry to form a considerable part of the black grouse diet throughout the year. Whilst this is true, the black grouse diet also closely reflects seasonal plant availability. During the spring cotton grass buds are a large part of their diet, whilst during the summer herbs, grasses, sedge and rushes are consumed. In the Autumn and winter months, heather makes up almost their entire diet, particularly for males. Yet, as noted by Black Grouse UK (2007) and Natural England (2010), winter berries found on shrubs and small trees such as hawthorn and rowan can also provide food in the winter. Any grazing occurring on these areas should aim to allow vegetation to flower and set seed (Adamson, 2007).	17 Blanket Bog 18 Upland grassland	No guidance No guidance • Light grazing • Mosaic of suitable upland habitats including heather moor, bog, rough/damp grassland and scattered trees • Presence of heather and bilberry • Areas of tall (>40cm) rush or heather cover • Short grazed pasture on moorland edge	Habitat mapping Habitat mapping Habitat mapping, X, Y or U plots X, Y or u Plots Habitat mapping

During the breeding season, hens require long heather or tall areas of rush (>40cm) for nesting and cover (Adamson, 2007; RSPB, n.d. (a)). Both Baines (1994) and Starling-Westeberg, (2001) found habitats such as damp/marshy grassland were particularly important as these provided rich, tall rushes ideal for nesting and rearing chicks. Lek sites tend to be on relatively flat, open pasture on moorland edges (or forest edges, glades and tracks). Most importantly these sites are characterised by short vegetation which is usually grazed (Adamson, 2007).			
Extensive heather blocks can be a barrier to chick movement and feeding (RSPB, n.d. (a)). As such, burning of heather is important to provide/maintain a mosaic of different patch ages which encourages the growth of young shoots (which black grouse feed on), as well as create structural diversity (Adamson, 2007; RSPB, n.d. (a)).	402 Additional Management Payment - Control burning	• Patches of burnt heather • Patch size between 0.25 and 1ha • Burning should not occur next to bracken or where juniper has been recorded • Burning should not occur where sphagnum capillifolium is present • <u>Mosaic of different heather patch ages and heights</u>	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping
On heather moorland, light grazing helps to maintain a varied structural mosaic of heather and rough grass (RSPB, n.d. (a)).	400 Additional Management Payment - Stock management 401 Additional Management Payment - Mixed grazing 411 Additional Management Payment - Reduce stocking	Minimal guidance	Unlikely to be measured

CHOUGH

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Good chough feeding sites must have short vegetation and bare ground whichs allows accessible foaraging for invertebrates. As such, short-grazed rough pastures are ideal due to having minimal vegetation cover and plentiful invertebrates. (Bullock et al. 1983; RSPB, 2014). In line with previous studies, one of the most recent studies by Whistehead et al. (2005) found choughs had a preference for habitats with a sward height of around 2cm with associated grazing (Whitehead et al. 2005). Choughs take invertebrates just below the surface of the ground and are reliant on short pasture (less than 5cm in height), soft soil and bare areas for feeding (Poole, 2003; RSPB, 2014). Removal of livestock is thought to be one of the main reasons for population decline as this has led to once close cropped sward becoming too tall or scrubbed over for the birds to feed (RSPB, n.d). Fuller & Ausden (2008) also recognise the issue of scrub expansion whcih causes a loss of habitat for choughs. Choughs tend to nest on coastal cliffs. In Wales. Whitehead et al. (2005) found choughs showed strongest slection for grazed habitats i.e coastal pasture during the breeding season. As such the provision of short pasture on on cliff tops and coastal slopes are particualarly important. Maintainance or	15 Grazed permanent pasture with no inputs 15 Grazed permanent pasture with no inputs	• Grassland maintained by grazing • Grassland maintained with a range of sward heights • At least 20% of the grassland must be less then 7 centimetres high and at least 20% of the grassland must be more than 7 centimetres high. • Pasture or improved land maintained by grazing • Grassland maintained with a range of sward heights • At least 20% of the grassland must be less then 7 centimetres high and at least 20% of the grassland must be more than 7 centimetres high. • Coastal/cliff slope grazed pasture • Presence of animal dung (particularly cattle) • Short sward height (0-5cm)	Habitat mapping Habitat mapping, X plot Habitat mapping Habitat mapping Habitat mapping, X plot Habitat mapping Habitat mapping X plot Habitat mapping, X Habitat mapping Habitat mapping plot

restoration of these area are therefore thought to be a priority. Numerous studies (e.g. McCracken & Foster, 1994 & Mackay, 1996) have observed grazing to be an additional benefit to feeding choughs because animal dung provides an important source of invertebrates throughout the year.			
Low intensity, maritime heath is important for choughs as this provides a rich source of invertebrates as well as short turf or bare ground vital for feeding just below the surface. Maritime heathland which Is periodically burnt is also thought to be ideal, whilst grazing by livestock is vital in maintaining suitable feeding habitat (Bullock, 1983; Wildlife trust, n.d). Choughs breeding on Ramsay off the coast of Pembrokehshire have been observed to also feed in areas where the turf is very short; such areas of which were found amongst the coastal heather. The vegetation is kept close-cropped by constant grazing, trampling by visitors and rabbit grazing (Cowdy, 1973). The coast of Holyhead has suffered from a lack of heather grazing over the decades and this had led to tall leggy heather stands and a profusion of gorse. As a reuslt, the once diverse heathland community has dwindled which has further led to the loss of foraging choughs. Ideally patches of dry heath, short sward and grazed pasture is needed to provide both short and long vegegtation suitable to support invertebrates and foraging choughs (Ratcliffe & Bateson, 2014).	115 Lowland dry heath with less than 50% western gorse 116 Lowland dry heath with more than 50% western gorse	• Whole Farm Code apply to all the land within this option. • Light grazing • No newly planted trees • Whole Farm Code apply to all the land within this option. • Light grazing • No newly planted trees • Mosaic of short vegetation and dry heath	 Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping
Choughs largely breed on the west coast of Wales, and need enclosed nest sites and well grazed cliff slopes or hillside to feed on. Choughs take invertebrates just below the surface of the ground and are reliant on	161 Grassland management for chough (feeding)	• Whole Farm Code apply to all the land within this option. • Grassland maintained by grazing	 Habitat mapping Habitat mapping, x plots

short turf, with bare areas for feeding (Poole, 2003; RSPB, n.d). Removal of livestock is thought to be the one of the main reasons for population decline as this has led to once close cropped sward becoming too tall or scrubbed over for the birds to feed (RSPB, n.d). Fuller & Ausden (2008) also recognise the issue of scrub expansion which causes a loss of habitat for choughs. Choughs utilise cliff faces and cliff tops with grazed, cliff-slope grassland being one of their preferred feeding area (Poole, 2003). A study by Ausden & Bateson (2005) studied the introduction of year round cattle grazing on 26ha area of formerly ungazed, semi-improved grassland at South Stack RSPB reserve, Anglesey. After 1 year of grazing, the estimated sward height was reduced from over 10cm to between 0-5cm in height. Consequently, the use of the area by feeding choughs increased by over 40% during the late winter and just under 30% in the early spring. The study therefore highlights the importance of cattle grazing. Not only does it show how suitable grazing management of an area can increase opportunites for feeding choughs during the breeding season, but it further demonstrates that choughs are reliant on short, open vegetation. Numerous studies (e.g. McCracken & Foster, 1994 & Mackay, 1996) have observed grazing have a beneifical to choughs becuase animal dung provides an important source of invertebrates throughout the year.		• 80% Sward between 3cm to 5cm throughout the year • Coastal/cliff slope grazed grassland • Low % scrub cover • Presence of animal dung, (particularly cattle)	Habitat mapping Habitat mapping, x plot X or Y plots
(CRoW Act definition of 'open country' – mountain, moor, heath and downland) Holyoak (1972) observed choughs breeding inland on hills and mountains in North Wales, some of which built their sheep wool, cupped nests on heather stems. Feeding was observed on boggy areas, grassland and	41A Grazing management of open country 41B Grazing management of open country with mixed grazing 16 Upland heath	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed No guidance	Habitat mapping Habitat mapping

hill pastures. On the Calf, Isle of Man choughs were also observed feeding in bare earth and rocky places around the heather. Numerous studies (e.g. McCracken & Foster, 1994 & Mackay, 1996) have observed grazing have a beneifical to choughs becuase animal dung provides an important source of invertebrates throughout the year.	18 Upland grassland	No guidance • Presence of animal dung, (particularly cattle)	X, Y & U plots
Suitable grazing management of an area can increase opportunites for feeding choughs during the breeding season (Ausden & Bateson, 2005). Furthermore, numerous studies (e.g. McCracken & Foster, 1994 & Mackay, 1996) have observed grazing have a beneifical to choughs becuase animal dung provides an important source of invertebrates throughout the year.	401 Additional Management Payment - Mixed grazing 411 Additional Management Payment - Reduce stocking	Minimal guidance	Unlikely to be measured
Unable to find evidence	117 Lowland wet heath with less than 60% purple moor- grass 118 Lowland wet heath with more than 60% purple moor-grass	Minimal guidance	
Unable to find evidence	401 Additional Management Payment - Mixed grazing 411 Additional Management Payment - Reduce stocking	Minimal guidance	

CORN BUNTING

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
During the summer, adult birds collect insects to feed their chicks. Grass margins at the edge of cereal fields are suitable for this purpose because, in comparison to the adjacent crop; margins support higher invertebrate numbers (Brickle et al. 2000; Vickery et al. 2002). Grass margins sown with cocksfoot are particularly effective as these create a tussocky sward which typically support relatively high invertebrate numbers (Brickle et al. 2000; Vickery et al. 2002; RSPB, n.d). Corn buntings prefer large, open arable and mixed farming (RPSB, n.d). Mason & Macdonald (2000) found corns buntings has a strong preference for selecting territories without hedges, as well as generally avoiding hedges particularly hedges over 1.5m tall. Furthermore, the RSBP (n.d) suggests margins should be created in arable fields away from tall hedges and treelines.	26 Fixed rough grass margins on arable land 26B Rotational rough grass margin on arable land 27 Fallow margins	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated • New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated • New fallow crop margin adjacent to cereals, oil seed rape, linseed, maize or roots • Between 2-8m wide • Can be rotated • Open arable and mixed farmland • Margins away from tall hedges and treelines • Tussocky grassland	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping, A & M plots
Corn buntings prefer large, open arable and mixed farming. During the breeding season, adult corn buntings nest in cereal crops and feed on seeds and grain, whilst the chicks are reared mainly on insects (RSPB, n.d). During the	28 Retain winter stubbles	• Light grazing • No maize • Natural regeneration of grass and broadleaved plants after harvest • No undersown stubble • Can be rotated	Habitat mapping Habitat mapping; A & M plots A & M plots A & M plots

summer, adult birds take insects from crops to feed their chicks; spring-sown barley is one of the habitats predominantly used. During the winter, the retention of stubble after harvest, particularly from unsprayed crop provides essential winter food in the form of broadleaved seeds (Brickle et al. 2000; RSPB, n.d). Study by Perkins et al. (2012) found weed abundance is strong predictor of nesting territory. Weeds provide ground cover at the base of crops which helps to conceal nesting chicks. Furthermore, weeds host a range of invertebrates which are vital chick-food. Areas which are heavily sprayed with insecticide and herbicide are less used as foraging areas because these eliminate invertebrates and broadleaved weeds (Brickle et al. 2000; RSPB, n.d). As such, breeding productivity is suppressed due to the reduction of nests concealment and chick food (Perkins et al. 2012).	31 Unsprayed spring sown cereals retaining winter stubbles 163 Unsprayed spring sown barley crop for corn bunting (nesting & feeding) 32B Plant unsprayed root crops on improved land	• On improved land only • Natural regeneration of grass and broadleaved plants after harvest • No grazing between harvest and 1st January • Can be rotated • Spring sown barley crop established between 15 March – 15 April each year • Barely to cover at least 2ha and be at least 75m wide • Only on improved land • White turnips, soft yellow turnips, hardy yellow turnips, swedes or fodder beets established before 1 July • Invasive or alien weeds to be spot treated I.e. spear thistle, creeping thistle, curled dock, broad-leaved dock, ragwort, Japanese knotweed or Himalayan balsam. • Grass buffer, minimum of 2m wide established if crop is situated next to watercourse • <u>Weeds in crop understory</u> • <u>Open arable and mixed farmland</u>	Unlikely to be measured Habitat mapping A & M plots Habitat mapping Unlikely to be mapped Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping; A, M & X plot Habitat mapping A, M & X plot Habitat mapping
During the summer, adult birds take insects from crops to feed their chicks; areas of set-aside are one of the habitats predominantly used for this purpose (Brickle et al. 2000; RSPB, n.d).	33 Establish a wildlife cover crop on improved land	• On improved land only • 4m wide seed bed established for crop • Crop cover to be at least 80% cereals with at least one of the following; mustard, rape or linseed.	Habitat mapping Habitat mapping Habitat mapping; A & M plot

In winter, birds flock together and mainly feed on seeds (particularly cereal grain) in areas with plenty of food such as cover crops and winter stubble (RSPB, n.d).	34 Unharvested cereal headland 34B Unfertilised and unsprayed cereal headland	• No maize • Only on improved land • 3-6m wide cereal headland established along edge of crop • Only on improved land • 3-6m wide cereal headland established along edge of crop • Can be rotated	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured
Corn Bunting declines have been linked previously to changes in cropping, notably localized reductions in the area of cereals grown (Donald et al. 1994) and the increasing trend for autumn sowing of cereals (Brickle & Harper 2002). Because winter cereals are harvested 3-4 weeks earlier than spring cereals, late-summer nesting habitats are often removed in the modern farming landscape, restricting female Corn Buntings to just one brood (Brickle & Harper 2002). Autumn-sowing also removes the opportunity for overwinter stubbles, which are important foraging habitats for Corn Buntings outside the breeding season (Perkins et al. 2008).	162 Unsprayed autumn sown cereal crop for corn bunting (nesting & feeding)	• Plots to cover at least 2ha and be at least 75m wide • Sown crop established before 31 October • <u>Numerous studies suggest autumn sowing is unsuitable</u>	Habitat mapping Unlikely to be measured
Corn buntings prefer large, open arable and mixed farming (RPSB, n.d). Insects for chicks during the summer can be found in rough, tussocky grassland (RSPB, n.d).	175 Management of rough grassland; enclosed land	• Minimal or no scrub • At least 75% of grasses >20cm high • <u>Open arable and mixed farmland</u> • <u>Tussocky grassland</u>	Habitat mapping, X plots Habitat mapping, X plots Habitat mapping Habitat mapping, X plot

CURLEW

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
CRoW Act definition of 'open country' – mountain, moor, heath and downland. Curlew are associated with low disturbance and breed in upland areas of open moorland, rough and damp pastures and boggy ground. Nesting occurs in wide variety of vegetation types but usually select relatively tall vegetation withn a tussock of rough pasture (Haworth & Thompson, 1990; RSPB, n.d. (c)). A study by Pearce-Higgins & Grant (2006) found curlew abundance tended to be greater on plots where vegetation structure was relatively heterogeneous. A further report by Pearce-Higgins et al. (2006) found curlews in the Peak district had an association with intermediate vegetation heights, with the highest densities of curlews being found in areas where mean vegetation height was approx' 30cm; a height of which reflects the vegetation found in structurally diverse moorland. Grazing, inparticular mixed grazing of moorland helps to achieve a mosaic of taller,tussocky vegetation and shorter grassy areas ideal for breeding (RSPB, n.d (c)). Whilst breeding occurs on moorland, curlews instead prefer to feed on large surrounding agriculutral fields. No curlew without chicks was observed feeding on the moorland and curlews with chicks preferred to fly short distances to feed in fields closest to the moors i.e. at the edge of the moor. The choice to feed in large fields was linked to increased visibility when looking out for	41A Grazing management of open Country 41B Grazing management of open country with mixed grazing 16 Upland heath 17 Blanket Bog 18 Upland grassland	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed No guidance No guidance No guidance • <u>Heterogeneous vegetation structure</u> • <u>Damp soil</u> • <u>Moorland with marginal, large agricultural fields</u>	Habitat mapping Habitat mapping X, Y & U plots Soil cores Habitat mapping

predators; pastures were the main field type utilised (Glenn, 1998).			
Studies on the east coast have focussed on changes in bird numbers on sites experiencing saltmarsh reclamation (Goss-custard & Yates, 1992) and salt marsh managed realignment (Atkinson et al. 2004), both of which have recorded curlews using saltmarsh sites.	21 Grazed saltmarsh 21B Management of grazed saltmarsh with mixed grazing	• Grazing by cattle, sheep, goats or ponies • Grazed marshes: at least 20% of the sward should be under 10 centimetres and at least 20% over 10 centimetres in height. • Grazing by cattle, sheep, goats or ponies • Grazed marshes: at least 20% of the sward should be under 10 centimetres and at least 20% over 10 centimetres in height.	Habitat mapping Habitat mapping, X plots Habitat mapping Habitat mapping, X plots
In 2007, a five year project at the RSPB's Lake Vyrnwy reserve saw the reintroduction of grazing to rush-dominated moor, as well as the installation of fencing to prevent the trampling of nests by livestock (Jonhstone et al. 2012).	164 Grassland management for curlew (nesting & chick feeding)	• Grassland maintained by grazing • From 1 April to 15 July 25% of the sward must be less than 5cm in height, 25% of the sward must be between 20cm and 30 cm in height, the remaining 50% of the sward must be < 20cm in height. • Maintain thinly scattered rush cover at no more than 30% of the area, • No large dense blocks of rush • No tree planting	Habitat mapping Habitat mapping; X plot Habitat mapping; X & Y plot Habitat mapping Habitat mapping

Adult curlews have been observed foraging on permanent pastures, rough grazing and hay meadows. But importantly, curlews have a preference towards large fields close to moorland (Glenn, 1998).	165 Grassland management for curlew (adult feeding)	• Grassland maintained by grazing • From 1 April to 15 July 80% of the sward must be less than 5cm in height • From 31 July to 15 March of the following year at least 20% of the sward must be less than 7cm in height and 20% of the sward must be more than 7cm in height • Maintain thinly scattered rush cover no more than 30% of the area • No large dense blocks of rush • Large fields at the margin of moorland	Habitat mapping Habitat mapping; X plot Habitat mapping; X plot Habitat mapping; X plot Habitat mapping Habitat mapping
Nesting occurs in a wide variety of vegetation types, but in unimproved haycrops tall, sparse vegetation is slected for nesting. Late cut meadows (mid July onwards) can be important for nesting birds. Furthermore, leaving damp corners of the meadow uncut is beneficial as these can provide a feeding area for the unfledged chicks (RSPB, n.d. (c)). Curlews prefer open, undisturbed areas and generally aovid nesting close to trees, hedgerows and shrub cover (RSPB, n.d (c)); Wilson et al, 2004). In Finland, curlews showed an preference for tall vegetation (25-45cm), especially haymeadows. This was expected as taller vegetation can provide both good areas to forage as well as shelter for chicks and nest from predation (Valkama et al. 1998).	166 Haymeadow management for curlew (nesting)	• Grassland maintained by grazing and hay cutting • Between 5% & 10% left uncut every year after July • 80% of aftermath sward height of the grasses between 5cm and 15cm high • Sward should never be cut below 2cm • No tree planting	Habitat mapping Habitat mapping Habitat mapping; X plot Habitat mapping; X plot Habitat mapping

GOLDEN PLOVER

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Rank, tall heather >12cm in height is thought to impede movement and foraging, as such these areas are avoided both by adults and chicks. Instead, during the summer months, a mosaic of short, open vegetation such as, short heath, wet flushes and blanket bog is ideal for breeding (Whittingham et al. 2000; Whittingham et al. 2001; RSPB, n.d. (d). Furthermore vegetation associated with these habitats including heather, bilberry, crowberry and cotton grass all provide invertebrates essential for feeding chicks (Pearce-Higgins & Yalden, 2004). Furthermore this is a tendency for chicks to use marshy patches of *Juncus effusus* for cover (Percival & Smith, 1992; Whittingham et al. 2001). Golden plovers require moorland for nesting and rearing chicks. However, since habitat selection is partly driven by availability of food, breeding adult golden plovers (particularly during the incubation period) prefer to forage in enclosed fields situated at the moorland boundary. Due to grazing and enrichment of enclosed agricultural fields (e.g. short pasture and grassland), these have higher earthworm and tipulid larvae densities in comparison to upland habitats (Ratcliffe, 1976; Whittingham et al. 2001; Pearce-Higgins & Yalden, 2003). To maintain structural variability extensive gazing of moorland is suggested. Not only will this retain an open habitat structure by preventing the colonisation of trees, but it will also break up patches of uniform heather stands (Whittingham et al. 2000).	16 Upland heath	No guidance	
	17 Blanket Bog	No guidance	
	18 Upland grassland	No guidance	
	41A Grazing management of open country	• Gazing of 'open country'	Habitat mapping
	41B Grazing management of open country with mixed grazing	• Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping
		• Mosaic of short heath, blanket bog, marsh and wet flushes on Moorland	Habitat mapping
		• Key upland species – *Calluna vulgaris, Eriophorum vaginatum*, Empetrum nigrum, Vaccinium myrtillus and *Juncus effuses*	X, Y & U plots
		• Enclosed grassland at the moorland edge	Habitat mapping

Grazing of grassland maintains a short sward; not only does this aid movement and makes foraging more efficient (Ratcliffe, 1976), whilst enrichment of grassland, (partly from manure) results in higher earthworm and tipulid larvae densities in comparison to upland habitats (Ratcliffe, 1976; Whittingham et al. 2001; Pearce-Higgins & Yalden, 2004). Since habitat selection is partly driven by availability of food, breeding adult golden plovers (particularly during the incubation period) prefer to forage in enclosed fields situated at the moorland boundary. Due to grazing and enrichment of enclosed agricultural fields such and improved grassland and pasture, these have higher earthworm and tipulid larvae densities in comparison to upland habitats (Ratcliffe, 1976; Whittingham et al. 2001; Pearce-Higgins & Yalden, 2003).	167 Grassland management for golden plover (feeding)	• Grassland maintained by grazing • At least 80% of sward must be <5cm in height between March and June • Maintain thinly scattered rush no more than 10% of the area • No dense blocks of rush • <u>Enclosed grassland fields at the moorland edge</u>	Habitat mapping Habitat mapping; X plot Habitat mapping; X plot Habitat mapping Habitat mapping

LAPWING

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
CRoW Act definition of open country – mountain, moor, heath and downland. Grazing helps maintain short sward and sparse tussocky structure ideal for lapwings (RSPB, n.d).	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed	Habitat mapping Habitat mapping
Lapwings are known to breed on grassland with low stocking densities, yet it is vital that the sward is short with some bare ground patches for feeding, as well as tussocks of taller vegetation (i.e rush) to provide cover for the chicks (Natural England, 2011; RSPB, n.d). This is refelcted in a study by Galbraith (1988) which found choice of nesting habitat was not influenced by food availability in the immediate vicinity of the nest site, but instead by the amount of vegetation cover to favour concealment of the incubating adult and eggs. However vegetation which is too tall and rank hinders the movement of chicks in search of food. The preference for large fields and the avoidance of close trees or tall woody linear features (WLF) which support predators is thought likely to be a predator-avoidance strategy (Galbraith, 1988). Findings by MacDonald & Bolton (2008) and Sheldon et al. (2007) both found that predation rates decreased the further nests were from the field boundaries. As such both suggest that lapwing management shoud be targeted in the centre of the largest field to ensure suitable nesting habitat is created as far as possible	168 Grassland management for lapwing (nesting & feeding)	• Grassland maintained by grazing • By 31 March at least 80% of the sward must be less than 5 centimetres high. • From 1 May to 15 July at least 50% of the sward must be less than 7 centimetres in height, and at least 10% of the sward must be over 10 centimetres high. • Maintain thinly scattered rush cover at no more than 30% of the area. • No large dense blocks of rush • Between 5% and 10% of the area should be bare ground • No newly planted tree • <u>Large, open fields with centre away from WLF and woodland edges</u> • <u>Light grazing</u> • <u>Shallow pools (scrapes) and shallow linear wet features (drains)</u> *(creating scrapes is part of capital works)*	Habitat mapping Will not be captured Habitat mapping, X plots Habitat mapping, X plots Habitat mapping, X plots Habitat mapping, X plots Habitat mapping Habitat mapping Habitat mapping Habitat mapping?

from field boundaires, thus helping to minimise predation rates. Recent efforts to re-create wet grassland and improve wader breeding success has foccussed on reinstalling wet features.Damp areas or shallow muddy water margins (i.e. scrapes) provide an abundane of food. They are therefore important feeding areas for lapwings in early spring before the breeding season, and later on, for their chicks. (Eglington et al. 2010; Natural England, 2011; RSPB, n.d). Providing sufficeint invertebrate prey can be sustained during the pre-fledging period, chicks with access to wet features are able to grow rapidly and maintain body condition thus enhancing chances of survival (Eglington et al. 2010). Linear wet features are an increasingly widely used tool for re- wetting grassland and research has shown waders prefer nesting close to linear features wet features. Furthermore, linear wet features do not elevate the risk of predation of nests or checks (Eglington et al. 2009).		Very similar to above prescription, Natural England (2011) suggests the ideal sward structure to have; • Little dead plant litter. • Scattered bare ground covers up to 10% of the area. • Short sward, less than 5 cm tall covers more than 70% of the area. • Scattered clumps 10-15 cm, or occasional taller tussocks make up about 20% of the sward.	X plots Habitat mapping, X plots Habitat mapping, X plots Habitat mapping, X plots
Lapwings prefer to nest in large, open fields with short but variable vegetation structure on spring-tilled arable land (RSPB, n.d). Galbraith (1988) reported on the difficulties of finding nests when located on the bare soil of spring cereal fields due to lack of features to help pin-point the nest location. It was therefore thought that visual hunters/predators such as crows may suffer the same difficulty. Numerous studies have found the success of lapwing nesting appears to be strongly influenced by predators. As such lapwings prefer to nest away from boundary features such as hedgerows, trees and woodland edges as these support predators (Sheldon et al. 2007;	169 Unsprayed spring sown cereals, oil seed rape, linseed or mustard crop for lapwing (nesting)	• New area of unsprayed spring sown cereals • Crop established in a cultivated seed bed • No under sowing of crop • Bare ground • Large, open field situated areas away from WLF and woodland edges • Spring sown cereal field adjacent to pasture or grassland	Habitat mapping Habitat mapping Habitat mapping, X plot Habitat mapping, X plot Habitat mapping Habitat mapping

Chamberlain et al. 2009). Findings by Sheldon et al. (2007) and Macdonald & Bolton (2008) both suggest that lapwing management shoud be targeted in the centre of the largest field, as such suitable nesting habitat is created as far as possible from field boundaires which would help to minimise predation rates. Whilst lapwings tend to nest in arable fields, parents will often walk their chicks onto grazed pasture to feed (RSPB, n.d). Galbraith (1988) observed that food supply within the immediate vicinty of the nest was not seen an important factor for nesting lapwings. Hay fields and pastures supported significantly higher number and biomass of invertebrates than cereal fields. As such birds preferred to nest in cereal fields close to pasture.			
Sheldon et al. (2007) assessed the effectiveness of an agri-environment prescription, option 1B (overwinter cereal or linseed stubble followed by a spring/summer fallow –similar to glastir) designed to provide rough bare ground that lapwings prefer as nesting habitat. 85% of the 34 lapwing nests successfully hatched at least one chick on cultivated fields. This could be maximised by locating plots a sufficient distance from field boundaries to reduce predation. Nests >50m away from the nearest field boundary were found to have a higher daily survival rate. Finally, since the option stipulates that all agriculutral operations should be completed by the 20th March, no nests were lost because agricultural operations. Lapwings start nesting from mid-March, prescription possibly encouraging mechanical operations to occur too late in the month.	170 Uncropped fallow plot for lapwing (nesting)	• Establishment of fallow plot before 14 April each year • New plot left as bare ground • Plot allowed to regenerate naturally • Large, open fields • Fallow plots situated in open areas away from WLF's and woodland edges • Cereal field adjacent to pasture or grassland	Habitat mapping Habitat mapping, X plot X plot Habitat mapping Habitat mapping Habitat mapping

Chamberlain et al. (2009) similarily studied the use of fallow plot options within two English agri-envrionment schemes.Lapwings occured on about 40% of the 212 fallow plots studied and plots with >50% bare ground had 14% higher occupancy rate than plots with <50% bare ground. Lapwing occurrence decreased if there was woodland adjacent, as such it's thought that nesting occurrence could be increased through better management and placement of plots i.e. situated in open areas away from woody boundary features. Galbraith (1988) observed that food supply within the immediate vicinty of the nest was not seen as an important factor for nesting lapwings. Hay fields and pastures supported significantly higher number and biomass of invertebrates than cereal fields. As such birds preferred to nest in cereal fields close to pasture/grassland and ulitmately move their chicks.			
Declines in wader populations in the UK are thought to be driven primarily by changes in agricultural grassland management, particularly decrease in wetness due to improvement of drainage (Bolton et al. 2007). Linear wet features are an increasingly widely used tool for re- wetting grassland and research has shown waders prefer nesting close to linear features wet features. Furthermore, linear wet features do not elevate the risk of predation of nests or checks (Eglington et al. 2009). A further study by Eglington et al. (2010) identified wet features on managed wet grassland. In comparison to the wet grassland, wet footdrains and wet pools supported the highest invertebrate biomass. Furthermore chicks observed feeding in these wet	403 Additional Management Payment - Re-wetting 404 Additional Management Payment - Re-wetting (improved land)	• Re-wetting of agricultural land • Re-wetting of improved land • Shallow pools (scrapes) and shallow linear wet features (drains)	Vegetation composition change – X plots or Y plots Vegetation composition change – X plots or Y plots Habitat mapping

features were also found to have higher foraging rates and biomass intake. The creation of shallow wet features appeared to be highly effective at providing neccessary food needed to sustain foraging chicks and enhancing chick growth, particulalry later in the season. As such reinstalling of wet features in grassland is thought likely to improve breeding success.			

RING OUZEL

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Ring ouzels primarily breed in mature/tall heather (40-50cm in height) on steep slopes, gullies and crags (RSPB, n.d. (e)). The decline in ring ouzel abundance was more likely if grass-heather mosaics were initially extensive; the loss of heather for nesting is thought to affect predation risk and be a critical factor leading to breeding site desertion, particularly at lower altitudes (Buchanan et al. 2003). A study by Sim et al. (2013) found juveniles used grass-heather mosaics; short grass provided suitable foraging means whilst being in close proximity to heather which provided cover from predators. However, during the late summer, juveniles moved to taller, heather-dominated, berry-rich areas to satisfy their foraging needs. Bilberries, crowberries and rowan were particularly favoured when foraging and are an important food source in the late summer as birds stock up on food before migrating (Sim et al. 2013; RSPB, n.d. (e)). Bracken patches provide ring ouzels with cover when foraging and are sometimes used for nesting (RSPB, n.d (e))	16 Upland heath	No guidance • Heather 40-50cm in height on steep slopes, gullies or crags • Grass-heather-bracken mosaic • Presence of Bilberry, crowberry and rowan	 Habitat mapping Habitat mapping X, Y or U plots
(CRoW Act definition of 'open country' – mountain, moor, heath and downland) Ring ouzels are summer visitors and are usually found above 250m altitude. Ring ouzels breed on moorland and establish their home ranges in areas dominated by patches of their preferred vegetation types. An 'ideal	41A Grazing management of open country 41B Grazing management of open country with mixed grazing	• Grazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed • Moorland • Grass-heather-bracken mosaic	Habitat mapping Habitat mapping Habitat mapping Habitat mapping

home range mosaic' might involve 10-15 discrete habitat patches in an area of 5-10 ha, comprising 50% grazed grass, 15% heather, 10% bilberry, 5% rock/bare ground, 5% bracken, 5% moss, 5% rough grass and 5% other (Burfield, 2002). Bracken patches provide ring ouzels with cover when foraging and are sometimes used for nesting (RSPB, n.d. (e)). Bird shift from foraging for invertebrates in grassland during nesting to forage at higher altitudes on heather-rich moorland berries, particularly bilberry, crowberry and rowan (Sim et al. 2013; RSPB, n.d. (e)).		• Heather 40-50cm in height on steep slopes, gullies or crags • Presence of Bilberry, crowberry and rowan	Habitat mapping X, Y or U plots
Similarly to choughs, the presence of livestock is essential to prevent the growth of tall rank vegetation which reduces habitat suitability for feeding. Ring ouzels select short, grazed grassland for foraging during the nesting period due to the high availability of earthworms (favoured food). Foraging occurs within 450m of the nest during this period. Furthermore the short sward is thought to increase predator avoidance and facilitate the movement of birds along the ground (Burfield, 2002).	161 Grassland management for chough (feeding)	• Whole Farm Code apply to all the land within this option. • Grassland maintained by grazing • 80% Sward between 3cm to 5cm throughout the year	 Habitat mapping Habitat mapping; X plot
Ring ouzels select open, short, grazed grassland for foraging during the nesting period due to the high availability of earthworms (favoured food). Foraging occurs within 450m of the nest during this period. Furthermore the short sward is thought to increase predator avoidance and facilitate the movement birds along the ground (Burfield, 2002).	171 Grassland management for ring ouzel (feeding)	• Grassland maintained by grazing • From April to July the sward must be <5cm in height • From August to March at least 20% of sward must be <7cm in height and at least 20% must be >7cm in height • Thinly scattered rush cover no more than 30% of the area • No dense blocks of rush • No new trees planted	Habitat mapping Habitat mapping Habitat mapping; X plot Habitat mapping; X plot Habitat mapping Habitat mapping

TURTLE DOVE

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Decrease in turtle dove numbers in the UK is thought to be due to degradation of habitat quality, rather than solely habitat loss; particularly as management techniques are more intense and damaging (Browne et al. 2004). Turtle doves primarily nest in hedges or scrub over 4m tall (RSPB, 2008). Tall, overgrown thorny scrub (principally hawthorn and blackthorn) are the preferred species used by nesting turtle doves (Brown & Aebischer, 2004; Browne, 2005). Nestling turtle doves have a preferred hedge height and width of 4.5m and 3m. As such, sympathetic management should allow for this (Browne & Aebischer, 2001). In comparison to areas of scrub and woodland, both Mason & Macdonald (2000) and Browne (2005) found hedges tended to be the least favoured habitat. Yet, Browne et al. (2004) found turtle density was positively related to increases (per unit area) of hedgerow and woodland.	3 Create a wildlife corridor – Establish wooded strip on improved ground	• New WLF on improved land • WLF width between 5-15m • New stock proof fencing • Species richness ; ≥ 5 woody species • ≤ 25% native conifers • Thorny species - blackthorn and hawthorn	Habitat Mapping –Linears D plots Linears & Fence condition B & D plots B & D plots Habitat mapping; B, D & H plots
Turtle doves primarily nest in hedges or scrub over 4m tall (RSPB, 2008). Tall, overgrown thorny scrub (principally hawthorn and blackthorn) are the	23 Allow small areas of improved land in corners of fields to revert to rough grassland and scrub	• New area of rough grassland in field corner (Max size 0.35ha) • New length and location of stock proof fence	Habitat mapping Linears and fence condition

preferred species used by nesting turtle doves (Brown & Aebischer, 2004; Browne, 2005). Mason & Macdonald (2000) found turtle doves had a stronger preference towards scrub habitats than woodland.		• Thorny species - blackthorn and hawthorn • Scrub >4m in height	Habitat mapping; B, D & H plots Habitat mapping
Turtle doves have been recorded in crop fields but found mainly feeding on weed strips around the edge of the field. (Mason & Macdonald, 2000; Browne & Aebischer, 2001). Evidence from plant surveys suggest unmanaged areas such as set-aside and other rough ground adjacent to crop is more suited as a foraging area, particularly as these areas can support short, open and weed rich cover (Browne & Aebischer, 2001; Browne, 2002). Browne (2002) found feeding generally took place on short (average 12cm in height) and sparse (average 40%) vegetation cover. Turtle doves have also been observed feeding on short vegetation (<10cm), and sparse (<20%) vegetation. Adult diets have been determined through faecal samples; cultivated seeds principally wheat and oil-seed rape, formed 60% of their diet with the remainder being made up by a mixture of Common Fumitory, Knotgrass and Common Chickweed. Nestling diets are similar in that 74% of seeds eaten where from cultivated plants, with the rest being made up of weeds (Browne,	27 Fallow margins	• New fallow crop margin • 2-8m wide margin on improved land; must be situated next to cereals, oil seed rape, linseed, maize or roots • Can be rotated • Short vegetation; average 12cm or less • Sparse vegetation; average 40% cover or less • Weed rich fallow margin • Key weed species - Common Fumitory, Knotgrass and Common Chickweed	Habitat mapping Habitat mapping Unlikely to be measured Habitat mapping; A or M plot Habitat mapping; A or M plot A & M plot A & M plot

2002).Similar results were found by Browne & Aebicher (2001).			
Turtle doves feed on stubble after harvest to pick at the fallen grain fallen from the crop. As such, leaving stubble uncultivated until the end of August provides seed food (Browne, 2002; RSPB, 2008). Key feeding areas visited by turtle doves receive no application of herbicide. Herbicides remove broad leaf weeds that provide seed food for turtle doves, as such intensively farmed landscape are not suitable for foraging (Browne, 2002; RSPB, 2008).	31 Unsprayed spring sown cereals retaining winter stubbles	• On improved land only • Natural regeneration of grass and broadleaved plants after harvest • Light grazing after 1 January • Can be rotated	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured
Both adult and juvenile turtle doves feed exclusively on seeds, particularly cultivated seeds such wheat and oil-seed rape (Browne, 2002). Establishing a wildlife crop corner is thought to be a good way of introducing seed-rich habitat into grassland. Using a low seed rate helps to create an open crop which not allows weeds to germinate and seed, whilst also allowing ground access (Browne & Aebicher, 2001; RSPB, 2008). Optimal feeding areas visited by turtle doves receive no application of herbicide because these remove broad leaf weeds that provide seed food for turtle doves. As such intensively farmed landscape are not suitable for foraging (Browne, 2002; RSPB, n.d).	33 Establish a wildlife cover crop on improved land 34 Unharvested cereal headland 34B Unfertilised and unsprayed cereal headland	• On improved land only • 4m wide seed bed established for crop • Crop cover to be at least 80% cereals with at least one of the following; mustard, rape or linseed. • No maize • Only on improved land • 3-6m wide cereal headland established along edge of crop • Only on improved land • 3-6m wide cereal headland established along edge of crop Can be rotated • <u>Sparse vegetation; average 40% cover or less</u>	Habitat mapping Habitat mapping A &M plot A & M plot Habitat mapping Habitat mapping Habitat mapping Habitat mapping A &M plot

		• Short vegetation; average 12cm or less • Weed In understorey • Key weed species - Common Fumitory, Knotgrass and Common Chickweed	A & M plot A& M plot
Study by (Murton et al. 1964) observed a small percentage of turtle doves feeding in root crop fields with weeds.	32B Plant unsprayed root crops on improved land	• On improved land only • Crop established could be white turnips, soft yellow turnips, hardy yellow turnips, swedes or fodder beets • Grass buffer (minimum 2m) if option located next to a watercourse • Key weed species - Common Fumitory, Knotgrass and Common Chickweed	Habitat mapping Habitat mapping; X plot Habitat mapping X plot
Unable to find evidence	30 Unsprayed spring sown cereals or legumes	• On improved land only • No clover in crop understorey • Can be rotated	Habitat mapping X plot Unlikely to be measured

TWITE

Evidence obtained from Literature	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Reed (1995) studied habitat uses of twites during and after breeding; post-breeding twites would switch to foraging in in lightly grazed pastures once the chicks had fledged around July. Study by Reine (2006) also found that twites preferred improved fields without livestock or fields with low stocking rates. This was because flower cover was greatest in these fields.	15 Grazed permanent pasture with no inputs 15C Grazed permanent pasture with no inputs and mixed grazing	• Grassland maintained by grazing • Grassland maintained with a range of sward heights • At least 20% of the grassland to be less then 7 centimetres high and at least 20% of the grassland to be more than 7 centimetres high. • Maintained by grazing • Grassland maintained with a range of sward heights • At least 20% of the grassland to be less then 7 centimetres high and at least 20% of the grassland to be more than 7 centimetres high. • Pasture close to moorland edge	Habitat mapping Habitat mapping Habitat mapping; X plot Habitat mapping Habitat mapping; X plot Habitat mapping; X plot Habitat mapping
CRoW Act definition of 'open country' – mountain, moor, heath and downland. In Britain, twite are typically found in upland areas and nest on the moorland edge (Brown et al. 1995). They have a strong preference for nesting in the litter under patches of bracken or in tall heather on steep sloping ground McGhie et al. 1994; Brown, 1995; Reine, 2006). Nests have also been found in rocky areas such as cliffs and quarries (Reine, 2006).	41A Grazing management of open country 41B Grazing management of open country with mixed grazing 16 Upland heath 17 Blanket Bog 18 Upland grassland	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed No guidance No guidance No guidance	Habitat mapping Habitat mapping

Moorland is rarely used to collect seed food (Wilson & Wilkinson, 2010), however twite will use burnt Molina grassland where they feed on fallen Molina seeds (Orford, 1973; Raine, 2006). Moorland heterogeneity is needed for twites to breed successfully; extensive patches of upland grasses through over grazing and burning should be avoided (Raine, 2006). Over-grazing, particularly by sheep can quickly cause a loss of heterogeneity on heath moorland, as grasses will tend to dominate. Presence of twite has been shown to be negatively related to the presence of livestock (Raine, 2006). However light grazing (ideally cattle or mixed) is needed to prevent succession of moorland in scrub or woodland, as well as to maintain different heather heights (Raine, 2006; RSPB, n.d. (f)).		• Moorland edge • Large patches of heather • Bracken patches on steep slopes • Burnt Molinia patches	Habitat mapping Habitat mapping Habitat mapping Habitat mapping
Twites have a strong preference for foraging in hay meadows with a high density of dandelion (*Taraxacum*) and sorrel (*Rumex acetosa*) flowers (McGhie et al. 1994; Raine, 2006). The birds feed almost exclusively on unripened dandelion seeds until the food source runs out, after which they switch to feeding almost entirely on sorrel. However, once the meadows are cut, the fields are no longer visited (McGhie et al. 1994).	22 Existing hay meadows 126 Lowland unimproved neutral grassland - reversion (hay cutting)	• Field shut off from livestock before 15 May and closed for at least 10 weeks • Aftermath sward height - 80% of the grasses between 5- 15cm high • Grassland maintained by grazing and hay cutting • Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting • Grassland maintained by grazing and hay cutting	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Habitat mapping; X & Y plot Habitat mapping

In later studies, both Raine (2006) and Wilson & Wilkinson (2010) found annual meadow grass, dandelion, sorrel, autumn hawkbit and thistles each in turn make up a significant part of an adult and chick's diet from May to August. Seed-rich areas, particularly late-cut upland hay meadows should be provided within 2km of the moorland edge (Raine, 2006; RSPB, n.d. (f)).	132 Conversion from improved grassland to semi- improved grassland (hay cutting)	• Between 5-10% left uncut each year • 80% of grasses between 5-15cm high after cutting • Fields shut off to livestock by 1 May • Upland hay meadows close to moorland edge • Key Species – Annual meadow grass, Dandelion, sorrel, autumn hawkbit and thistles	Habitat mapping Habitat mapping; X ploy Habitat mapping Habitat mapping Habitat mapping; X & U plots
RSPB (n.d. (f).) suggests leaving 2m field margins as these can provide seed food for chicks throughout the summer.	26 Fixed rough grass margins on arable land	• New rough grass margin • Width of 2-8m on arable land • No grazing once established • Mix of tussock forming grasses • Cannot be rotated	Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured
	26B Rotational rough grass margin on arable land	• New rough grass margin adjacent to cereal, rape, linseed or root crop • Between 2-8m wide • Mix of tussock forming grasses • No grazing once established • Can be rotated	Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured
	27 Fallow margins	• New fallow crop margin adjacent to cereals, oil seed rape, linseed, maize or roots • Between 2-8m wide • Can be rotated	Habitat mapping Habitat mapping Unlikely to be measured
In Scotland, crop stubble, particularly from oil-seed rape and turnips are used as winter feeding ground for flocks of twite (Hancock & Wilson, 2003).	28 Retain winter stubbles	• Light grazing • No maize • Natural regeneration of grass and broadleaved plants after harvest • No undersown stubble	Habitat mapping Habitat mapping; A & M plots A & M plots A & M plots

		• Can be rotated	Unlikely to be measured
Since twites feed predominately on small-seeds of ruderal plants throughout the year (even when feeding their chicks), they are susceptible to land use change, particularly reduced seed availability (Wilkinson & Wilson, 2010). As a result of agricultural intensification, both cereal and root crops in the uplands have declined. This is thought to have removed key weed species needed to sustain twite (Raine, 2006). Extensive farmland surveys in Scotland found root crops (such as turnips) and their associated weed species have been shown to be an important winter food resource for Twite (Hancock & Wilson, 2003).	30 Unsprayed spring sown cereals or legumes 31 Unsprayed spring sown cereals retaining winter stubbles 32B Plant unsprayed root crops on improved land	• On improved land only • No clover in crop understorey • Can be rotated • On improved land only • Natural regeneration of grass and broadleaved plants after harvest • No grazing between harvest and 1st January • Can be rotated • On improved land only • Crop established could be white turnips, soft yellow turnips, hardy yellow turnips, swedes or fodder beets • Upland cereal and root crops close to moorland • Weeds in crop understorey – dandelion and sorrel	Habitat mapping X plot Unlikely to be measured Habitat mapping A & M plots Habitat mapping Unlikely to be mapped Habitat mapping Habitat mapping; A & M plots Habitat mapping Habitat mapping, A & M plots
Wildlife crop cover can provide a mix of seed-bearing plants needed for foraging twites (RSPB, n.d. (f)).	33 Establish a wildlife cover crop on improved land	• On improved land only • New ≥ 4m wide seed bed on improved land • New cover crop have ≥ 80% cereals including either mustard, linseed or rape • No maize	Habitat mapping Habitat mapping Habitat mapping; A & M plots Habitat mapping
Unable to find evidence	34 Unharvested cereal headland	• Only on improved land • 3-6m wide cereal headland established along edge of crop • Only on improved land	Habitat mapping Habitat mapping Habitat mapping Habitat mapping

	34B Unfertilised and unsprayed cereal headland	• 3-6m wide cereal headland established along edge of crop • Can be rotated • 3-6m wide cereal headland established along edge of crop • Only on improved land • 3-6m wide cereal headland established along edge of crop • Can be rotated	Unlikely to be measured Habitat mapping Habitat mapping Habitat mapping Habitat mapping Unlikely to be measured
Unable to find evidence	Option 120 - Lowland unimproved acid grassland / 121 Lowland unimproved acid grassland - reversion (pasture) 123. Lowland unimproved neutral grassland – pasture / 125 Lowland unimproved neutral grassland - reversion (pasture) 133 - Lowland marshy grassland /134 Lowland marshy grassland; reversion (pasture)	• Grassland maintained by grazing • 75% grasses and herbs between 3cm-20cm in height between May and September • Grassland maintained by grazing • In sheep grazed areas, varied sward height maintained between 10cm – 20cm • In none sheep grazed areas, varied sward height maintained between 5cm – 20cm • Grazing of Marshy grassland • 80% of grasses (excluding rushes) between 10cm-30cm in height	Habitat mapping Habitat mapping; X & U plot Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping; X & Y plots Habitat mapping Habitat mapping; X, Y & U plots
Unable to find evidence	159 Grassland managed with no inputs between 15 October and 31 January	• Grassland maintained by grazing • Sward height at least 5cm	Habitat mapping Habitat mapping; X plot
Unable to find evidence	175 Management of rough grassland - enclosed land	• Minimal or no scrub on grassland • At least 75% of grasses >20cm high	Habitat mapping X plot Habitat mapping; X plot

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Annual Knawel

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Agricultural Crops</u> *Scleranthus annuus* can grow as an annual or biennial plant and occurs on dry sandy grounds both in arable habitats as well as on disturbed soil in dry heathland, commons, waste places, and occasionally river or coastal shingle (Preston et al. 2002). It main occurrence is on sandy acidic soils but it can also occasionally be found on soils containing carbonates (Salisbury 1961). It is a very small-statured species with low levels of competitiveness and is mainly found under conditions of low fertility, as expressed by its Ellenberg N score of 4 (Hill et al. 2004). As *S. annuus* germinates over winter (Muller 1978), autumn cultivation is recommended. Because of its lack of competitiveness, un-cropped cultivated margins and unfertilised conservation headlands sown with winter cereals may be a good strategy to provide optimal conditions for this species. Flowering time is from June to August (Fitter & Peat 1994). *S. annuus* tends to form a long-term persistent seed bank (Thompson et al. 1997), and can thus persist locally during periods of unsuitable management.	27. Fallow margins	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated	Habitat mapping, A & M plots
	28. Retain winter stubbles	• New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping & X plots

		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	

N.B. Anything highlighted in red in the 'Specific response variable' column is thought to contradict the highlighted evidence obtained from the literature.

Broad-fruited Cornsalad

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Agricultural Crops</u> *Valerianella rimosa* is an annual species that almost exclusively grows in arable habitats (Wilson 2008). It is found on a range of soils, often as part of species-rich communities, and tends to be associated with other rare arable spp. such as *Scandix pecten-veneris*, *Ranunculus arvensis*, and *Silene gallica* (Wilson 2008). Little is known about its seed bank persistence, but its seed is likely to be moderately long-lived when buried in soil (Wilson 2008). *V. rimosa* germinates both in autumn and in spring, and accordingly, it is found both in autumn crops and in spring crops (Wilson 2008). Its July-August flowering time (Fitter & Peat 1994) is relatively late. Early harvest dates should thus be avoided, to enable *V. rimosa* to complete its life cycle. Being very uncompetitive, *V. rimosa* does best in nutrient-poor (field margin) situations with an open crop canopy (Wilson 2008), which is also reflected in its high Ellenberg L (=light) value of 8, and its low Ellenberg N value of 3 (Hill et al. 2004). Accordingly, management of fields as conservation headlands may benefit the species. Nitrogen fertilization, on the other hand, via enhancing competition from the crop canopy, tends to have detrimental effects on its performance, e.g. in winter wheat (Wilson 1999). No information is available about its susceptibility to herbicides, but it is likely to	27. Fallow margins 28. Retain winter stubbles	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated • New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping, A & M plots Habitat mapping & X plots

be affected by the majority of broad-spectrum herbicides (Wilson & King 2003).		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • <u>Stubble left after crop harvest</u> (to allow comnpletion of life cycle) • <u>Arable dicot richness</u> • <u>Occurrence of other rare arable spp.</u>	

Chamomile

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Heathland *C. nobile* is a perennial growing on moderately acidic soils in short grassy vegetation, usually on relatively acid, sandy or gley soils that are seasonally wet, usually in winter (Winship 1994; Winship & Chatters 1994. Its habitats include herb-rich grassland, e.g. on commons and pastures, turf, and more recently also on sports fields (Winship 1994). It requires sufficient disturbance, e.g. through grazing, mowing or trampling, to keep vegetation short and open (Winship & Chatters 1994). Under close trampling, it can achieve more than 50% cover, due to its ability to spread vegetatively under such conditions (Kay & John 1994). It is uncompetitive, as indicated by a high Ellenberg L value of 8 (Hill et al. 2004), but can persist in moderately nutrient-rich sites, as long as disturbance keeps competitive species in check. It is also found in maritime grassland, e.g. on cliffs, where exposure and salt spray keep the sward short (Winship & Chatters 1994). In addition to reproducing via seed, the species is well-adapted to spread clonally via creeping stems, particularly in situations where grazing pressure is very high (Winship & Chatters 1994). Little is known about its seed longevity. While it is assumed that it can persist as seed in the soil at least for limited periods (Plantlife 2013), no seed was detected in samples from underneath several populations (Kay & John 1994). Threats include the cessation of grazing, as well as the drainage of suitable habitats (Winship & Chatters 1994). Suitable restoration measures include the	41A Grazing management of open country 41B Grazing management of open country with mixed grazing 119 Lowland heath habitat expansion - establishment on grassland	• Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed • Adhere to permitted range of seasonal grazing levels: 1 April – 30 June: 0.00-0.10 LU/ha 1 July – 30 Sept.: 0.00-0.05 LU/ha 1 Oct. – 31 Mar.: 0.00*-0.01 LU/ha	Habitat mapping Habitat mapping (Specifics of grazing won't be captured)

reinstatement of cattle and/or pony grazing on heathland, targeted scrub control in overgrown habitat, and the reversion of pasture to heathland (Plantlife2013). Sheep and rabbit grazing, on the other hand, do not usually produce the poached ground preferred by this species (Winship 1994). Where grazing is impractical, mowing may help to maintain existing populations of *C. nobile*, but not necessarily those of rarer species that may be associated in herb-rich grassland (Winship 1994).			
C. nobile is a perennial usually growing on relatively acid, sandy or gley soils that are seasonally wet, usually in winter (Winship 1994; Winship & Chatters 1994. Threats include the drainage of suitable habitats (Winship & Chatters 1994).	403 Additional Management Payment - Re-wetting	• Mean Ellenberg F moisture score	
Unable to find evidence	20 Management of lowland and coastal heath 20B Management of lowland and coastal heath with mixed grazing 44 Mechanical bracken control 115 Lowland dry heath with less than 50% western gorse 116 Lowland dry heath with more than 50% western gorse 117 Lowland wet heath with less than 60% purple moor- grass 118 Lowland wet heath with more than 60% purple moor-grass 139 Lowland bog and other acid mires with <50% purple moor-grass 140 Lowland bog and other acid mires with >50% purple moor-grass 141 Lowland bog and other acid mires; restoration (no grazing)	N/A	N/A

	142 Lowland bog and other acid mires; reversion (pasture) 400 Additional Management Payment - Stock management 401 Additional Management Payment - Mixed grazing 402 Additional Management Payment - Control burning 411 Additional Management Payment - Reduce stocking		

Corn Buttercup

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Agricultural Crops</u> *Ranunculus arvensis* is an annual species of arable land on a wide range of soil types including loams, sands, clays, and chalk (Preston et al. 2002). It is often found with other rare weeds such as *Scandix pecten-veneris* and *Valerianella rimosa* (Smith 1994). *R. arvensis* is susceptible to many broad-spectrum herbicides and has experienced a rapid decline from the 1940s onwards in response to the spread of synthetic herbicides (Potts & Vickerman 1974). Improved cleaning of crop seed has also played a role in its decline (Salisbury 1961). It has been suggested that traditionally, seed dispersal occurred through grazing of the stubble by lifestock (Schneider et al. 1994). While Salisbury (1961) suggested that buried fruits can remain viable for many years, studies of soil seed banks (Thompson et al. 1997) and burial experiments (e.g. Wilson 1990) suggest that the species may only have a short-term persistent seed bank. Germination takes place in autumn and winter (Wilson & King), and for this reason, autumn-sown crops are more suitable than spring-sown crops (Schneider et al. 1994). Crop rotations with a strong focus on spring-sown crops should thus be avoided at sites where the species is present (Schneider et al. 1994). *R. arvensis* tends to be suppressed at high cereal tiller densities (Schneider et al. 1994). Its rather shallow root system (Kutschera 1960) enables it to tolerate saturated soil conditions in late winter and spring.	27. Fallow margins	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated	Habitat mapping, A & M plots
	28. Retain winter stubbles	• New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping & X plots

Flowering occurs from June to July (Fitter & Peat 1994). A late harvest will promote self-seeding, as fully ripened fruits detach from the plant more easily, whereas an early harvest tends to result in seed removal from the site (Schneider et al. 1994). If there is sufficient soil moisture after harvest, re-growth can occur from subsidiary branches, and for this reason, it may be beneficial to leave the stubble after harvest (Schneider et al. 1994).		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • Stubble left after crop harvest (to allow re-growth) • Arable dicot richness • Occurrence of other rare arable spp.	

N.B. Anything highlighted in red in the 'Specific response variable' column is thought to contradict the highlighted evidence obtained from the literature.

Cornflower

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Agricultural Crops *Centaurea cyanus* used to be an annual weed mostly of arable land, particularly on sandy and rather acidic soils (Smith in Stewart et al. 1994, growing mainly in crops of rye (Smith 1994). Now, it occurs more often in waste places and other disturbed sites, either as garden escape or sown as part of wildflower mixes (Preston et al. 2002). Its true distribution as naturally-occurring species is now obscured by widespread introduction and colonisation from introduced populations (Wilson 2007). Main germination season is September to October, with some further germination after spring cultivations (Wilson & King 2003). Acccordingly, it is found both in winter crops as well as in spring crops, but autumn-germinated plants in winter crops are usually bigger and produce more seed than plants in spring crops (Schneider et al. 1994). Its decline is linked to a range of factors, including seed cleaning, habitat loss (Wilson 2007), and a poor ability to compete with cereal crops sown at high densities (Svensson & Wigren 1982). C. cyanus also is sensitive to a range of herbicides (Preston et al. 2002), but due to its ability to emerge from greater depths, it is less sensitive to pre-emergence herbicides (Schneider et al. 1994). Seed is short-lived under field conditions, and usually, only a small fraction of seeds remains viable for more than one year (e.g. Svensson & Wigren 1985; Barralis et al. 1988). Accordingly, the species does best in crop	27. Fallow margins 28. Retain winter stubbles	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated • New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping, A & M plots Habitat mapping & X plots

rotations with a strong focus on winter crops (Schneider et al. 1994) which boost its re-seeding. Re-seeding is further promoted by late harvest dates (Schneider et al. 1994).		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	

Large-flowered Hemp-nettle

Indicators Obtained from Evidence	**Target Species and Glastir Measures**	**Specific Response Variables**	**GMEP Survey Data That Captures Measure or Target**
Agricultural Crops Summer annual weed of cultivated, marginal and waste ground (Preston et al. 2002). In the British Isles, *Galeopsis speciosa* is often found within root crops, especially potatoes, on peaty soils (Preston et al. 2002). The seeds require cold stratification (Karlsson et al. 2006) prior to seedling emergence in spring, which usually occurs around late April (Salisbury 1961). Information on seed bank persistence is scarce, but short-term persistence of up to five years appears likely (Thompson et al. 1997) Flowering is relatively late, between July and September (Fitter & Peat 1994), and the species is likely to benefit from leaving stubbles after harvest. *G. speciosa* is considered to be one of the more vigorously growing species of arable weed that can hold its own relatively well in competitive arable crops (Hakansson 2003). This is also reflected in the species having been assigned a relatively high Ellenberg N value of 7 (Hill et al. 2004). While there is no published evidence from UK studies on its response to various cultivation practices, in eastern Europe, *G. speciosa* has been found to be negatively affected by stubble removal after harvesting, as well as by early pre-winter ploughing, by inter-row cultivation of tilled crops, and by herbicide application (Sokolova 2009).	27. Fallow margins 28. Retain winter stubbles	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated • New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping, A & M plots Habitat mapping & X plots

		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • Stubble left after crop harvest (to allow completion of life cycle) • Autumn cultivation not too early (to allow completion of life cycle)	

N.B. Anything highlighted in red in the 'Specific response variable' column is thought to contradict the highlighted evidence obtained from the literature.

Marsh Clubmoss

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Heathland *Lycopodiella inundata* is usually found on bare peaty, or occasionally sandy or silty areas, usually with a bare ground cover of about 30-60% (Headley 1994; Byfield & Stewart 2007). The margins of lakes are its natural habitat, where it grows in or immediately adjacent to the inundation zone (Byfield & Stewart 2007). Its most important semi-natural habitat are bare patches within extensively grazed heathland, and in Wales, sheep-grazed moorland represents one of the strongholds of the species (Byfield & Stewart 2007). In terms of substrate, it is mostly found on very acidic and oligotrophic, moist to wet soils in fully exposed situations (Rasmussen & Lawesson 2002). In wet heathland, it is often associated with *Rhynchospora alba* and with *Rhynchospora fusca*, which along with the purplish alga *Zygogonium ericetorum* may be good indicators of habitat suitability for *L. inundata* (Byfield & Stewart 2007). As *L. inundata* is a pteridophyte, its life cycle is formed of two independent stages, including a free-living gametophyte stage in addition to the much more conspicuous sporophyte stage. The gametophyte is superficial and green and requires a several years to reach maturity (Headley 1994). The sporophyte is a short-lived prostrate perennial plant that grows at the tips of evergreen branches whose older sections fragment after about two years, resulting in clonal reproduction (Headley 1994; Byfield & Stewart 2007). According to Headley (1994). The species often occurs as a pioneer (Rasmussen & Lawesson 2002) and can rapidly	119 Lowland heath habitat expansion - establishment on grassland 140 Lowland bog and other acid mires with more than 50% purple moor-grass	• Adhere to permitted range of seasonal grazing levels: Option 119: 1 April – 30 June: 0.00-0.10 LU/ha 1 July – 30 Sept.: 0.00-0.05 LU/ha 1 Oct. – 31 Mar.: 0.00*-0.01 LU/ha Option 140: 1 April – 30 Sept.: 0.20-0.30 LU/ha 1 Oct. – 31 Mar.: 0.00-0.10 LU/ha	Habitat mapping (specifics of grazing won't be captured)

colonise bare patches created by winter inundation, cattle poaching, peat cutting, or vehicle activity (Preston et al. 2002). It has been suggested that *L. inundata* reaches new sites through highly efficient dispersal of spores (Øllgaard 1985). In already-established populations, the main means of dispersal likely is clonal spread by fragmentation (Rasmussen & Lawesson 2002). Due to its slow, prostrate growth, with stems typically only growing about 3-6 cm per year (Byfield & Stewart 2007), *L. inundata* is a very poor competitor as succession proceeds (Rasmussen & Lawesson 2002). Repeated disturbance and erosion are key for its continued persistence at a site (Rasmussen & Lawesson 2002; Byfield & Stewart 2007). Threats include eutrophication and the cessation of suitable grazing regimes, as well as destruction of wetlands, e.g. due to drainage (Headley 1994; Rasmussen & Lawesson 2002). Traditionally, the practice of turf-cutting was beneficial to *L. inundata* (Byfield & Stewart), and accordingly, the use of sod cutting in wet heath restoration tends to positively affect *L. inundata* populations (Dorland et al. 2005). On sites where it already grows, protracted periods of uninterrupted traditional management, e.g. via extensive grazing, have been recommended (Byfield & Stewart 2007).			

Pillwort

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Heathland</u> *Pilularia globulifera* is a perennial fern of silty or peaty lake or pond margins and shallow, seasonally-dry ditches and pools, e.g. within heathland and upland grassland, but can also survive in deep water where it is occasionally found as a submerged aquatic (Jermy 1994; Scott et al. 1999). It is also occasionally found in man-made habitats such as old clay-pit workings and gravel extraction sites (Scott et al. 1999). Suitable waterbodies tend to be moderately acid and nutrient-poor, as also expressed by Ellenberg R - and N-values of 4 and 2, respectively (Hill et al. 2004). In a survey of Welsh upland pools, *Pilularia globulifera* was not found in pools with more than 0.005 mg/l nitrate or with a water pH of lower than 5.2 (Slater et al. 1991). A re-analysis of Slater et al.'s (1991) dataset by Wilkinson (1998) demonstrates that *P. globulifera* is predominantly found in pools where species richness of emergent plants is high. As a pioneer, *P. globulifera* requires bare ground, usually created by fluctuating water levels or disturbance, e.g. by cattle or horse trampling (Preston et al. 2002; Jermy 1994). It temporarily occupies such patches of bare ground until it is being ousted by competitive late-successional species (Jermy 1994). Colonization can occur locally through creeping rhizomes or across larger distances via the spreading of sporocarps on the feet of lifestock and waterfowl (Scott et al. 1999; Szczęśniak & Szlachetka 2008; Plantlife 2010). According to Jermy (1994), the gametophyte generation is only short-lived, and new sporophytes can emerge within 17 days of	20 Management of lowland and coastal heath 20B Management of lowland and coastal heath with mixed grazing 41A Grazing management of open country 41B Grazing management of open country with mixed grazing 119 Lowland heath habitat expansion - establishment on grassland 140 Lowland bog and other acid mires with more than 50% purple moor-grass	• Grazing by cattle, sheep, goats or ponies • ≥50% dwarf shrub species on lowland heath • ≥25% dwarf shrub species on coastal heath • ≤25% of heath burnt over 5 years • Gazing of 'open country' • Mixed grazing of 'open country'. Cattle and sheep must be grazed • Adhere to permitted range of seasonal grazing levels: Option 119: 1 April – 30 June: 0.00-0.10 LU/ha 1 July – 30 Sept.: 0.00-0.05 LU/ha 1 Oct. – 31 Mar.: 0.00*-0.01 LU/ha Option 140: 1 April – 30 Sept.: 0.20-0.30 LU/ha 1 Oct. – 31 Mar.: 0.00-0.10 LU/ha	Habitat mapping, X & U plots Habitat mapping Habitat mapping (specifics of grazing won't be captured)

spore germination. It has been suggested that sporocarps can persist at the bottom of pools or ponds (Plantlife 2010). While no direct evidence exists, Szczęśniak & Szlachetka (2008) have found that some of the sporocarps they collected did remain hard and closed for extended periods, which may facilitate sporocarp burial in the mud. Threats include habitat deterioration (e.g. due to the infilling of ponds, eutrophication, drainage, and the cessation of grazing) and destruction (e.g. due to the loss of ponds or heathland) (Scott et al. 1999; Plantlife 2010). At some sites, the spread of invasive alien species such as *Crassula helmsii* may pose a threat (Scott et al. 1999). Preservation of existing populations depends crucially on the maintenance of open site conditions, e.g. where suitable via grazing by cattle and horses (Plantlife 2010). Restoration efforts might include reinstatement of suiutable grazing regimes, and, in the case of ponds, dredging to the original profile (Plantlife 2010).			

Purple-ramping Fumitory

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Agricultural Crops</u> *Fumaria purpurea*, first described in 1902, is endemic to the British Isles (Pearman & Preston 1994). It is difficult to identify and its current mapped distribution may not accurately reflect its actual distribution (Lockton 2003). Literature describing its ecological requirements is scarce (Lockton 2003). The species is found across a range of habitats that are either disturbed or opened up by summer drought (Pearman & Preston 1994). In Wales, it is found in arable fields, as well as in gardens and allotments, on waste ground, in hedge banks, and earthy shore habitats (Lockton 2003). F*. purpurea* occurs mostly in spring-sown crops (Preston et al. 2002). The reason for this is likely a combination of *F. purpurea*, like the related *Fumaria officinalis* (Roberts & Feast 1973), being a spring-germinating species, and/or of it being too uncompetitive to do well underneath the canopy of autumn-sown crops, which would be in agreement with its relatively low Ellenberg N value of 5 (Hill et al. 2004). Nothing is known about its seed bank persistence, but it seems likely that like the closely related *F. officinalis* (Thompson et al. 1997), it may have seeds that remain viable for a long time when buried in soil. Flowering is relatively late, between July and October (Fitter & Peat 1994), suggesting that this species may benefit from leaving stubbles after harvest.	27. Fallow margins	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated	Habitat mapping, A & M plots
	28. Retain winter stubbles	• New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping & X plots

		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated •	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • Stubble left after crop harvest (to allow completion of life cycle)	

Red Hemp-nettle

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Agricultural Crops *Galeopsis angustifolia* is an annual species of arable fields that also occurs on coastal sands and shingle (Smith & Wilson 1994). In arable situations it is confined to light chalky soils that are well-drained (Wilson & King 2003). Its germination occurs entirely in the spring, and accordingly, *G. angustifolia* is restricted to spring crops (Wilson & King 2003). Its decline is partly due to a move away in agriculture from spring crops to winter crops (Preston et al. 2002), but also due to its susceptibility to many herbicides, and the increased use of N fertilizer and of nitrogen-demanding crop varieties (Wilson & King 2003). Little is known about its seed bank persistence, but according to Wilson & King (2003), its seeds are likely to be long-lived. *G. angustifolia* is late-flowering from July to October (Wilson & King 2003), and tends to grow rapidly after crop harvest, setting much seed in stubbles if these are left in late summer (Smith & Wilson in Stewart et al. 1994). It is therefore essential to leave the stubble after harvest. Arable populations have been shown to benefit from management of fields as conservation headlands (Sotherton 1990).	27. Fallow margins	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated	Habitat mapping, A & M plots
	28. Retain winter stubbles	• New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping & X plots

		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • Stubble left after crop harvest (to allow completion of life cycle) • Autumn cultivation not too early (to allow completion of life cycle)	

Shepherd's Needle

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Agricultural Crops</u> *Scandix pecten-veneris* is an annual species of arable land and only rarely found in other habitats (Preston et al. 2002). The majority of populations is now found on heavy calcareous clays (Wilson 2006), but historically, the species occurred on a wide range of soil types (Brenchley 1920). Germination occurs mainly in the autumn (October-November), with a small amount of germination in spring (Brenchley & Warington 1936; Wilson 1990). Accordingly, *S. pecten-veneris* is typically found in fields sown with winter cereals (Wilson 2006). Its flowering time of April to July (Fitter & Peat) is relatively early compared to other rare arable species, although spring-germinated individuals can be expected to flower much later than autumn—germinated individuals. This species is more competitive than other rare arable weed species and can cope better than these with more fertile conditions and enhanced levels of competition by the crop canopy. Accordingly, it can tolerate a certain amount of fertilizer application; however, experimental N applications in a winter wheat crop did nonetheless reduce plant densities (Wilson 1999). The species has been found to benefit from management of fields as conservation headlands (Sotherton 1990). Due to its relative competitiveness, it is not just found in species-rich vegetation in extensively managed crops where it co-occurs with other rare arable species, but	27. Fallow margins 28. Retain winter stubbles	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated • New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping, A & M plots Habitat mapping & X plots

also in species-poor vegetation in which other rare species cannot persist (Wilson 2006). *S. pecten-veneris* is susceptible to a wide range of broad-spectrum herbicides (Wilson 1990, 2006), but at the same time has shown resistance to a few herbicides (Wilson & King 2003). Its seeds are short-lived, and few seeds tend to persist for more than one year (Brenchley & Warington 1936; Wilson 1990). Accordingly, crop rotations with a strong focus on spring-sown crops should be avoided where the species is present. Ideal management for the species includes annual autumn cultivation, and crop harvesting only after *S. pecten-veneris* has set seed. A risk of *Scandix* seedlings being eliminated by pre-sowing cultivations in autumn (Smith 1994) may be avoided by early sowing of winter crops.		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	• New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	

N.B. Anything highlighted in red in the 'Specific response variable' column is thought to contradict the highlighted evidence obtained from the literature.

Small-flowered Catchfly

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
Agricultural Crops *Silene gallica* is an annual species growing predominantly in arable fields, but is also occasionally found at disturbed anthropogenic sites (wasteground etc.) and on sandy seashores (Preston et al. 2002). Some occurrences are due to its seeds being a contaminant of imported clover seed (Smith 1994). The majority of populations are found on nutrient-poor sands and sandy loams (Wilson & King 2003). Seed germination takes place predominantly in the autumn (Smith 1994), but some germination can also occur in spring (Wilson & King 2003). Nonetheless, in arable situations, *S. gallica* is mainly found in spring-sown crops, perhaps through its inability to compete with the dense crop canopy in some autumn-sown crops (Wilson 2008); in autumn-sown crops it can only persist if crop cover is sufficiently sparse (Wilson 2008). Some of the best populations of *S. gallica* are found in fields where root crops are a major component of rotations (Wilson 2008). Flowering time according to Fitter & Peat (1994) is from June to October). Populations can be successfully boosted by management of field margins within agri-environment schemes (Wilson 2008). *S. gallica* is a poor competitor and as such has suffered particularly strongly from N fertilization and improved crop varieties. While there is no information available on its susceptibility to herbicides, it appears likely that	27. Fallow margins	• New fallow crop margin on improved land • Situated next to cereals, OSR, linseed, maize or root crops • Fallow margin width of 2m to 8m • Cultivated annually in spring (before 15 May for cereals; before 31 May for maize; before 1 July for root crops) • Not cut before 1 August or until 14 weeks after sowing (whichever is later) • No fertiliser applied • Area must not be used as a track, but acceptable to allow machine access for hedgerow trimming • May be rotated	Habitat mapping, A & M plots
	28. Retain winter stubbles	• New winter stubble on improved land following a cereal crop • Straw removed within two weeks of harvest • Any grazing not to exceed 0.4 LU × ha^{-1} at any one time • No maize and no undersowing of the stubble • Any cut no earlier than 15 February	Habitat mapping & X plots

it is affected by the majority of broad-band herbicides (Wilson 2008). *S. gallica* has short-term seed bank persistence (Thompson et al. 1997), and should thus be able to tolerate crop rotations including crops that are unfavourable as long as every few years crops are planted that are compatible with its life cycle. These would be crops that are ideally cultivated in mid-autumn or in early spring. Due to low competitiveness, in competitive situations, it may be necessary to take measures to reduce the impact of competitive weeds (Wilson 2008).		• Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • Before 1 March, herbicides only applied to control notifiable weeds and invasive alien species • No manure stored on the area • No supplementary feed on the area • May be rotated •	
	30. Unsprayed spring sown cereals or pulses	• On improved land not certified organic • Non-maize cereal or pulse crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No undersowing • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated •	Habitat mapping & X plots
	31. Unsprayed spring sown cereals retaining winter stubbles	New unsprayed spring sown non-maize cereals retaining winter	Habitat mapping & X plots

		stubbles on improved land that has been cultivated previously and has not been certified organic • Crop established by cultivation in spring before 15 May • Crop not cut before 1 August or until 14 weeks after sowing (whichever is later) • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • Straw removed within two weeks of harvest • Grazing only from January onwards and not to exceed 0.4 LU × ha^{-1} at any one time • No undersowing • Any cut no earlier than 15 February • Ploughing, cultivating, and drilling only from 1 March onwards • No slurry application between harvest and 1 March • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated	
	34B. Unfertilised and unsprayed cereal headland	• New unfertilised and unsprayed cereal headland on improved land • Width of 3m to 6m	Habitat mapping, A & M plots

		• Cultivated annually in spring (before 15 May) • Crop not harvested or grazed before 1 August or until 14 weeks after sowing (whichever is later) • No fertilisers, manures, lime or slag applied • Other than the use of glyphosate to spray off vegetation prior to sowing, herbicides only used to control notifiable weeds and invasive alien species • No insecticide • No fungicides unless applied to the seed pre-sowing • No molluscicides unless drilled with the seed • May be rotated • Stubble left after crop harvest (to allow completion of life cycle)	

Three-lobed crowfoot

Indicators Obtained from Evidence	Target Species and Glastir Measures	Specific Response Variables	GMEP Survey Data That Captures Measure or Target
<u>Heathland</u> *Ranunculus tripartitus* is a winter annual species found in shallow seasonal bodies of water drying out in summer, such as ditches, ponds, and trackways. It is usually found over moderately base- and nutrient-rich clays and sands (Preston et al. 2002), e.g. within wet heathland and related communities (Byfield 1994). In Wales it tends to occur in areas dominated by M16 (Erica tetralix – Sphagnum compactum wet heath) and/or M25 (Molinia caerulea - Potentilla erecta mire) NVC communities. Also, it often occurs specifically in transition zones between improved or semi-improved pasture and M23 (Juncus effusus/acutiflorus - Galium palustre rush-pasture) (Lansdown & Evans 2000). *R. tripartitus* is sensitive to competition, and this is reflected in its low Ellenberg N value of 3 and its high Ellenberg L value of 9 (Hill et al. 2004). It requires open habitat that is maintained by disturbance, e.g. due to water level fluctuation, grazing and poaching by livestock (Byfield 1994). Large populations are usually found in situations where there is localised, heavy poaching of seasonally inundated areas (Lansdown & Evans 2000). *R. tripartitus* typically flowers between March and May (Fitter & Peat 1994), and completes its lifecycle before its habitat dries out in the summer. Main threats include the destruction of heathland, the cessation of disturbance activities such as grazing, and habitat modification, e.g. through drainage or infilling (Byfield 1994). While there is no data available on seed longevity, it is generally assumed that buried seeds can survive for at least several years, which would help populations to persist at degraded sites, allowing re-emergence once favourable conditions have been restored (Byfield 1994), e.g. through reinstatement of grazing or dredging of ponds to their original profile.	119 Lowland heath habitat expansion - establishment on grassland 140 Lowland bog and other acid mires with more than 50% purple moor-grass	• Adhere to permitted range of seasonal grazing levels: Option 119: 1 April – 30 June: 0.00-0.10 LU/ha 1 July – 30 Sept.: 0.00-0.05 LU/ha 1 Oct. – 31 Mar.: 0.00*-0.01 LU/ha Option 140: 1 April – 30 Sept.: 0.20-0.30 LU/ha 1 Oct. – 31 Mar.: 0.00-0.10 LU/ha	Habitat mapping (specifics of grazing won't be captured)

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Appendix 6.1

Modelling the impacts of Glastir options using the Bangor Carbon Footprinting tool

1. Model description

The Bangor CF takes real farm data on all inputs, land management practices (and history for Land Use Change) and monthly stock diary data to generate annual C footprints that are PAS 2050 compliant (unless soil and biomass C sequestration effects are included). It adopts Tier 1 emission factors for most N_2O and CH_4 emissions (enteric fermentation based on animal category numbers x average EFs; soil emission factors; manure storage by type *etc*…). But it includes a simplified Tier 2 estimate of soil C accumulation under grassland, and accounts for on-going C sequestration in tree biomass. A monthly stocking diary enables more accurate estimation of annual enteric fermentation (x animal numbers) and manure management (N excretion and CH_4 EFs). It uses a Life Cycle Analysis approach, and boundaries can include embedded GHG emissions associated with feed and fertiliser production and transportation to the farm.

1.1 Model outputs

The Bangor CF Tool outputs include: gases - enteric methane, manure methane, direct excreta, soil and manure heap N_2O; N_2O associated with nitrate leaching and N deposition (indirect N_2O); CO_2 from energy use; embedded greenhouse gas emissions associated with inputs (feed, fertiliser, agrochemicals, pharmaceuticals, significant consumables); and agricultural productivity. Above and below ground carbon annual increments in soils and biomass are modelled and reported separately from the system GHG emissions framework.

1.2 Recent applications of the model

The Bangor CF Tool was initially developed to assess the policy-relevant GHG emissions and carbon-sequestration impacts of a sustainable farming initiative in mid-Wales (Taylor et al. 2010); and for research into GHG emissions from mixed farming systems (Wyn Jones et al. 2011, Taylor et al. 2014). Further development took place under a previous Welsh Government funded project to assess the contribution of previous Welsh agri-environment schemes to the maintenance and improvement of soil and water quality, and to the mitigation of climate change (Taylor et al., 2012; chapter in Anthony et al 2012). It is currently being used in a number of projects to assess GHG impacts at the farm scale, including the annual variability in farm GHG emissions and the development of novel forage proteins for livestock production.

1.3 Emission Factors

The Bangor CF Tool generally uses IPCC Guidelines (2006) emission factors for calculating CH_4 and N_2O emissions from agriculture, maintaining compliance with PAS2050 where specific emissions factors are required for farm practices. Default emission factors are used with farm-specific management and productivity data (e.g. fertiliser use and dairy cattle milk yield) and livestock numbers and age classes are recalculated iteratively for each month of the farming year. Adherence to IPCC Guidelines means that model is consistent with UK Inventory methodology. Any additional emission factors are selected from review of the published literature on UK based field studies, in order to reflect as closely as possible the Welsh climate and natural soil attributes for N_2O - e.g. including the effects of temperature, atmospheric CO_2, pH, organic matter content, saturation and aeration.

1.4 N budget and N_2O emissions modelling

The Bangor CF Tool calculates the farm year organic N budget from livestock diaries using breed- and farm-specific animal growth rates; and mineral N from fertiliser formulation-use data. Stored manure (including incorporated bedding materials) and direct-deposition organic N (excreta and daily-spread manure) are modelled separately based on farm practice data.

Nitrate leaching, direct N and indirect N_2O emissions are calculated as emissions and losses from stored manures using IPCC standard Tier 1 methodology, with reference to farm storage practices (aerobic/anaerobic, lagoons etc.) specific to each animal type. Soil N_2O emissions are calculated from applied organic N (stored manure corrected for storage losses specific to store method), excreta organic N and applied mineral N (using a single EF for the N content of all fertiliser formulations applied, although formulation-specific EF's can be applied) per IPCC guidelines. Additional N_2O emissions are calculated per unit area of peat soils reported by the landowner and under management which includes N deposition (fertiliser, manure, grazing); corresponding to "managed peat soils" per IPCC recommendation. In the modelling of emissions from managed peat soils, where the IPCC standard temperate zone emission factor is 8 kg N_2O-N ha^{-1} (range 2-24 kg N_2O-N ha^{-1}) the Bangor model uses a much lower value from ECOSSE studies of North Wales peat soils (Smith et al 2010c), at 0.25 kg N_2O-N ha^{-1} (range -0.99-3.7 kg N_2O-N ha^{-1}).

1.5 Methane emissions modelling

The Bangor CF Tool calculates manure and excreta CH_4 emissions from the detailed livestock diaries using breed- and farm-specific animal growth rates. Monthly livestock numbers per animal type and age class are used with IPCC Tier 1 methodology and published relevant emissions rates for the relevant UK production systems. In order to avoid double-accounting, emissions from animals on the farm that remain the property of another holding are calculated separately: their direct emissions remain within the system boundary of their home farm, whilst soils and excreta emissions (N_2O and CH_4) are incorporated into the farm on which they are grazing. A common example of this is 'tack' sheep – livestock belonging to another farm, grazing in return for payment (usually £x per animal per week or month) and offering rotational grazing benefits to the destination farm.

1.6 Farm inputs

The Bangor CF Tool calculates embodied GHG emissions and transport emissions from point-of-sale to the farm gate for all farm inputs that can be identified and quantified. Farm inputs are identified during discussions with farmers, and details of their provenance, purchased amounts, transport method etc. collected in all available detail. PAS2050 allows the exclusion of inputs whose GHG impact totals less than 5% of the total emissions footprint, as long as the total GHG value of all excluded inputs remains below this 5% threshold. For each input, the embodied GHG emissions may be (in order of preference) a) extracted from relevant published PAS2050-compliant studies including IPCC databases; b) estimated using published or collected formulations or production data (relevant to fertilisers and animal feeds); c) estimated using data for farm exports calculated using the Bangor Tool during previous studies (relevant to bought-in livestock) or d) estimated using nearest-equivalent generic values from GHG emissions databases.

For inputs with annually-varying embodied GHG values, the published emissions value for the year in which the inputs were purchased is used (relevant to electricity and fuels). For complex inputs such as animal feeds, GHG emissions are calculated using feed formulation and individual ingredient provenance and published footprint data sourced in the same way as for other farm inputs.

1.7 Uncertainty

Citing a single precise figure as the output of a carbon footprinting exercise may be misleading as GHG calculations have to deal with issues of variability, uncertainty and subjectivity, each of which can reduce the accuracy and precision of the final result. For example, within the agricultural context, there is tremendous biophysical variability between farms producing the same products, and this can generate large differences in the calculated GHG emissions of the farm business. Welsh Lamb may be produced on an upland farm where there are very few inputs, but there is also low productivity per hectare; or on fertile lowland farms with higher unit productivity but more fertiliser input. Management also varies between farmers; and even neighbouring farms of the same type, e.g. dairy producers, can have different yields and GHG footprints which are partly a function of the personality and skills of the farmer. The weather can also have a large impact on the way a farm is managed. As a result the exact footprint of a farm may vary over time due to interactions between the climatic environment and the associated management decisions of the farmer. Finally, carbon footprints vary with the underlying soil type. As a result the underlying soil type of a farm can have a large impact on the final footprint for that farm. This sort of variation has not typically been reported in carbon footprints to date, but in the Welsh context Edwards-Jones et al. (2009b) suggest that the footprint from farms on organic (peat-derived) soils can be substantially greater than those on mineral soils.

In addition to genuine biophysical variation between farms and years there is also considerable uncertainty inherent in GHG emission factors. This uncertainty is related to the limitations of our understanding of ecosystem-level processes. Emission factors reported in standard databases are derived from studies using a range of system boundaries, data collection techniques, data definition and processing methodologies etc. The choice of emission factor database is a subjective process, while the variation between emission factors for the same process can introduce variability into the process of carbon footprinting. The scientific literature presents a range of emission factors for most processes. However, scientific understanding of these complex processes is limited, partly because their measurement is time-consuming and spatially and temporally variable. The IPCC approach to this problem has been to produce standard emission factors through meta-analysis of all the available experimental data. These may be applied worldwide or be relevant to large geographical regions, but can have limited relevance to local conditions.

In addition to variability and uncertainty, carbon footprints also include an element of subjectivity: the analyst is required to represent a real farm in a simplified form, which requires a series of simplifying assumptions to be made. It is important that analysts recognise the subjective nature of their activities. To date, few studies have tried to report this uncertainty and variability (exceptions include Lloyd & Ries 2008; Edwards-Jones et al. 2009). Similarly, many of the studies reported in the literature have used modelling approaches, rather than using real farm data: which does not allow for an assessment of differences between individual farms (e.g. Williams et al. 2006; Weiske et al. 2006; Hirschfeld et al. 2008).

The Bangor CF Tool retains uncertainty throughout the calculation process by presenting three sets of calculation results. The commonly cited value is calculated using the mid-values for all emissions factors, the value considered by the authors of source studies to be the most likely representation of an accurate value. In addition, a result is calculated using the maximum range values for all emissions factors (worst-case scenario) and a third result using the minimum range values (best-case scenario). These extreme values are likely to represent the absolute maximum range of possible GHG emissions produced by the farm system under analysis.

1.8 Arable crops and Land-use Change

Nitrous oxide emissions from arable land are calculated per IPCC guidelines for soil area, crop type and yield data collected from the farmer. Crop residues are modelled as removed (grazed, harvested) or incorporated (e.g. stubble ploughed-in) depending on stated management practices.

For land areas under management that has changed in the last 20 years, default land-use change values from Jones and Emmett (2009) and other relevant published literature are applied on an area basis. Relevant changes include C loss consonant with ploughing permanent grassland (to re-sow grassland or add to arable rotations); or C gains associated with woodland and hedgerow planting. C impacts of land-use change occur over a period of time (e.g. ploughing impacts occur in the first year, tillage changes over 10 years, etc) and the C impacts are modelled for one year’s net impact after the stated number of elapsed years. In order to avoid double-accounting, these soil GHG impacts of land-use change are included in the PAS2050-compliant emissions calculations, but soil areas subject to such changes are excluded from the C sequestration (soils) calculations.

1.9 Modelling carbon sequestration in soils and biomass

Carbon sequestration in soils and biomass is modelled independently of the PAS2050-compliant GHG emissions components of the Bangor CF Tool but uses the same Tier 1 approach and retains the same flexibility for scenario modelling. Calculations fall into the following categories:

a) ≥75% closed-canopy trees (woodland and forestry) over 20yo – modelled as woodland by area using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species or species mix) assuming stable soil carbon content. Timber extraction modelled as carbon losses sensitive to brash handling (burning, composting) and including litter decomposition.
b) ≥75% closed-canopy trees (woodland and forestry) under 20yo – modelled as woodland by area using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species or species mix) assuming increasing soil carbon content.
c) Dispersed or isolated trees including emergent from hedgerows – counted by landowner – are modelled as free-grown standards using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species mix).
d) Hedgerows are measured from aerial photographs in consultation with landowner. Hedges flailed in the sample year are assumed to maintain biomass equilibrium. Hedges not flailed in the sample year are modelled using growth increments for the equivalent area (length x width) of established alley-cropped short-rotation coppice. Boundary hedges (with

neighbouring farms) are assumed to be shared-ownership and 50% of their area excluded to avoid double-accounting un up-scaling results to national estimates.

e) Soil C sequestration is considered to be in equilibrium under arable and rotational (improved) grassland. For permanent grassland on mineral soils, a low-average default net ecosystem change value for UK grasslands of 0.24 t $ha^{-1}y^{-1}$ (range 0.04 – 0.44 t $ha^{-1}y^{-1}$, Janssens et al. (2005)) is used, pending further review of studies relevant to Welsh agricultural land. Buckingham et al. (2013) acknowledge the scarcity of relevant data for Welsh grassland but cites a similar rate of increase in SOC of 1 to 4 t ha^{-1} over 10 years as a consequence of manure application. For permanent grassland on organic soils default C sequestration rates for unmanaged peatlands are taken from Watson et al. (2000) (IPCC special report).

2. The Virtual Farm – scenario modelling using a completed farm model

2.1 GHG Mitigation modelling

A completed Bangor CF Tool is, in effect, a virtual model of an individual farm in a specified business year. The model is made very detailed to reflect that farm system and the management practices developed by the individual farmer, but it retains as calculation options all the alternative management practices specified by IPCC and encountered during previous Bangor farm modelling work. In consequence, it is possible to alter any component of the virtual farm and look for impacts of such changes. Potential mitigation methods affecting N_2O and CH_4 emissions would include manure storage (aerobic/anaerobic methods, digesters), fertiliser application rates, livestock types and stocking rates. Other possible mitigation options including dietary changes can be modelled by applying appropriate Tier 1 emissions factors from published literature or other model outputs (as % modifiers to soil emission rates, for example).

A range of other potential options for reducing GHG emissions can be applied to the virtual farm. These include modifying inputs such as energy use (including investment in self-generation and renewables) or livestock feeds. Feedstuff modification can be a simple reduction in feed purchase, or a change to feed formulation (e.g. reduced protein content, change of protein type) or feed provenance (switch from South American to EU-grown soya).

2.2 Productivity

The Bangor CF Tool also incorporates details of production (sales and exports by weight) for all farm produce in the sample year. These data are used to allocate GHG emissions to products for the purposes of product and supply-chain GHG footprinting beyond the farm gate. Allocation to products is compliant with PAS2050 and separates farm enterprises (direct and indirect emissions from cattle enterprise allocated to cattle products) as completely as possible. Notable exceptions include agrochemicals applied to pastures grazed by livestock from different enterprises (sheep and cattle), and energy inputs (electricity and diesel) which are allocated economically by enterprise sales revenues. 75-90% of total emissions can generally be allocated directly to the correct enterprises. A collateral benefit of these data is to investigate the potential impacts of mitigation or agri-environment scheme practices on production, with obvious benefits for predicting impacts of such schemes on national food security.

The Bangor Carbon Footprinting Tool outputs include: soil direct N_2O, indirect N_2O associated with nitrate leaching and N deposition, enteric CH_4, manure CH_4, CO_2 associated with electricity and energy use, embedded greenhouse gas emissions associated with feed and fertiliser production, agricultural productivity.

3. Applying Glastir options as modelled scenarios in complete farm models

To explore baseline greenhouse gas emissions from Welsh farms, we selected a subset of farms from a database of completed Welsh farm models produced in previous carbon footprinting studies at Bangor University. Farms were selected to represent a number of farming typologies representative of those found in Wales (in terms of size, altitude, stocking rates *etc*). Some of these farms had been in previous Welsh agri-environment schemes. Appendix 5.1 summarises the characteristics of these farms.

3.1 Glastir measures and assumptions

The Glastir measures which were assessed were the same as those used agreed by the steering group to be used in the ADAS modelling, *i.e.* Retain winter stubbles (AWE Option No. 28), Woodland margin extension (AWE Option No. 24), Grazing Management of Open Country (AWE Option No. 41A), Grazed Permanent Pasture – No Inputs (AWE Option No. 15), Create New Streamside Corridor – Both Sides / Tree Planting (AWE Option 9B). The assumptions used in developing the model runs were the same as those adopted for the ADAS model runs (see Year 1 Report - section 2.2). Change in soil and vegetation carbon stocks were not implemented in this application. A brief description of each measure is summarised below:

3.1.1 Grazed Permanent Pasture – No Inputs ("Zero Inputs") requires that no manufactured or organic fertiliser nitrogen is applied to permanent grazed grassland. Grassland is maintained using grazing stock to remove the entire year's grass growth (with no supplementary feeding of livestock). This requires a reduction in nitrogen fertiliser application to permanent grass, and a reduction in cattle and sheep stocking rate in proportion to reduction in effective forage production. Thus, CH_4 and N_2O emissions would be expected to be reduced accordingly.

The modelling assumed a reduction of N inputs to zero for selected areas (marginal land parcels) adding up to 1/3 of grassland or 18ha of improved /semi-improved grassland, according to Welsh Government farm entry statistics. N inputs were adjusted relative to the proportion of the farm impacted, and stock numbers (% across all year) reduced relative to the proportion of farm impacted. The assumption that fertiliser reductions occurred on only one-third of the permanent grass area is different to that used by the ADAS model, and is a little closer to reality. These stock changes were based on previous data on farms with/without fertiliser use, e.g. for beef this modification would be from a stocking rate of 1.4 LU on fertilised grass to 1.1 LU on non-fertilised grass. This impacts on direct, indirect and manure emissions. Feed, feed delivery, bedding, bedding delivery, pharmaceuticals, plastics *etc.* were also adjusted according to reductions in stock numbers.

3.1.2 Grazing Management of Open Country ("Open Country") aims at reducing stock numbers on farms stocked to their forage carrying capacity (based on forage production) to levels conducive with maintenance and restoration of habitat quality, and would reduce livestock numbers (and hence reduce CH_4 emissions from ruminant and manure sources, as well as N_2O associated with N in excreta and less fertiliser N production and use).

Specific modelling reduced stock levels to ‘sustainable’ levels defined by Welsh Government. This meant reducing N use of zero for improved grassland and adjusting stocking rates accordingly (using approach outlined above). This effects direct, indirect and manure emissions – with reduced requirements for feed, bedding, pharmaceuticals, plastics *etc*.

3.1.3 Woodland extension (“Woodland Margin”) is aimed at existing grassland and arable land, with often the existing fence between agricultural land and woodland being replaced 6m into the field. This results in reduced nutrient (N and P) input to the field (and should result in reduced soil N_2O emissions, and greenhouse gas emissions associated with feed and fertiliser manufacturing), and an assumed proportional reduction in the number of stock that can be carried (reduced enteric and manure CH_4 emissions). In terms of sources of greenhouse gas emissions, less fertiliser nitrogen would be required and fewer stock carried.

This measure requires farms with woodland bordering grassland or arable land. This was not the case for many of the farms selected for this modelling assessment. For those that did, affected areas were calculated, and reductions in stock numbers and associated fertiliser, feed, bedding, pharmaceuticals, plastics applied.

3.1.4 Create New Streamside Corridor (“Riparian Margin”) requires the fencing of an average area of 7 square metres per 1 metre length of watercourse (shared between both sides of the water course, hence an average buffer strip width of 3.5 m). The area must be fenced and native trees planted. The primary aim of this measure is to intercept particulates and enhance infiltration of pollutants in surface runoff. But the reduction in the agricultural land area will results in reduced cattle and sheep stocking rates (in proportion to reduction in effective forage production), and a reduction in the quantity of manufactured fertiliser nitrogen applied. Hence CH_4 and N_2O emissions would be expected to be reduced accordingly. There would also be prevention of direct excretion by animals using the watercourse for drinking water or cooling, and a reduction in bank-side erosion. This measure requires farms with streams bordering grassland or arable land. This was not the case for many of the farms selected for this modelling assessment. For those that did, affected areas were calculated, and reductions in stock numbers and associated fertiliser, feed, bedding, pharmaceuticals, plastics *etc.* calculated.

3.1.5 Retention of winter stubbles is primarily aimed at reducing the mobilisation of particulate pollutants due to protection of soil from raindrop impact, and some reduction in nitrate leaching associated with reduced mineralisation from later soil disturbance (ploughing) and uptake of N by weed species/volunteer grasses. However, after consideration of the modification in land, livestock and input management changes involved with this measure, it was clear that there was insufficient management change which the Bangor Carbon Footprinting Tool could model.

3.2 Baseline characteristics of the selected farm models

Baseline greenhouse gas emissions and carbon sequestration estimates for the example farms are summarised in Appendix 5.2. The warming potential of the different gases involved are standardised against the warming potential of carbon dioxide over 100 years in the atmosphere; they are expressed in kg CO_2 equivalents or CO_2e.

In the common pattern of ruminant livestock enterprises the main source of emissions is methane, which is 40 to 51% of emissions and primarily from enteric fermentation. The dairy and mixed farms (with dairy cattle) are at the higher end of the range, reflecting the high ruminant emissions associated with dairy production (**Table 5.2.1**).

Standardising emissions by land area (**Table 5.2.2**) allows a more direct comparison between farm types. Beef and sheep farms tend to be extensive rather than intensive and this is reflected in proportionally lower 13-18% embodied GHG emissions from inputs (feed, fertiliser, bedding etc); the dairy and mixed farms use more land treatments and imported feeds and their embodied inputs are higher at 24-30% of GHG emissions. Most farms buy-in small numbers of replacement animals per year; the high emissions in the beef group are due to Farm 5 which is a *beef finisher*, without adult cattle and buying-in all livestock rather than breeding and rearing young-stock.

Nitrous oxide emissions are modelled from stored manure, emissions from excreta and emissions from soil in response to N applications (fertiliser, manure and excreta). For most farms N_2O emissions represent about 20% of total GHG emissions.

Carbon sequestration estimates were made for woodland and scattered trees, hedgerows and soils; on some farms there is an additional component for land under changed management (land-use change) where this change affects net C storage, such as conversion of grassland to woodland or establishing permanent grassland on arable land (**Table 5.2.3**). The most important component of C-sequestration is the soil under permanent grassland: although sequestration rates per ha are low (the values used in this model are conservative) they are by far the largest sequestration resource on the farm because livestock farms have a very high proportion of their land under permanent pasture. The impact of arable management on soil C-sequestration can be seen on the dairy and mixed farms - where more arable is grown (cut forages) and short-term leys are used, and regular tillage negates soil C sequestration. On dairy farms, soil under grassland still represents the majority of C storage but is only 62% of the total (**Table 5.2.4**).

Total GHG equivalent sequestered on the more intensive dairy and mixed farms represents about 10% of emissions: on the beef farms it is higher at 18% largely because these farms have more scattered trees. Sheep producers are the most extensive (low emissions per ha) and maintain hedgerows on all field boundaries, and their C sequestration averages 98%. This average is strongly leveraged by farm 1, where sequestration represents 2 ½ times GHG emissions; the average for the other sheep producers is just under 50% of emissions.

3.3 Results of modelling Glastir measures with the Bangor Carbon Footprinting Tool

3.3.1 Grazed Permanent Pasture – No Inputs

Reducing nitrogen inputs to grazed permanent grassland reduces the carrying capacity of the grassland, and therefore animal numbers carried by the farm. This option could be applied to 15 of the 16 farms; sheep farm 4 used no inputs to permanent grassland and livestock was already at or below the prescribed carrying capacity so no stock reductions could be applied. Beef farm 2 was registered Organic and had no N inputs to reduce; but stock numbers were reduced to bring them down to prescribed carrying capacity for the land areas affected.

Table 3.3.1. *Changes in N use and livestock numbers* – On most of the farms N use was reduced by 8-10%; the overall average was 12%. Sheep numbers reduced by 5% and cattle by 10%. Reducing livestock numbers has a consequential effect on modelled productivity, with lamb sales down by 5%, beef by 8% and milk by 10%.

Table 3.3.1 and 3.3.2. *Changes in GHG emissions* – Modelling links changes in animal numbers to farm inputs such as feed purchases as well as 'downstream' emissions from soils and the livestock itself. Overall, GHG emissions for the 16 farms reduced by an average of 7%, or 107 metric tonnes of CO_2 equivalent per annum. The changes were distributed across farm inputs such as feed and fertiliser purchases (-1%), embodied GHG in imported livestock (-7%), N_2O emissions from manure, excreta and soils (-1% and -2%), methane emissions (-3%) and CO_2 from lime application (-8%). It is noteworthy that reducing inputs and bought-in stock will impact on the markets and producers of youngstock, extending the influence of the scheme option beyond the boundaries of the participating farm.

Table 3.3.3 and 3.3.4. *Changes in C sequestration* – this scheme option affected land use primarily through the effects of land-use change, which in this case increases soil C sequestration under grassland by removing and reducing nitrogen inputs. Applied inorganic nitrogen stimulates carbon loss to atmosphere by increasing soil bacterial activity and reducing plant diversity. Nitrogen in manure and excreta has a similar effect but its impact is reduced compared with synthetic N because manures also contain organic carbon sources. Land-use change C sequestration on the farms was very small in the baseline assessments, and increased by between 16 and 31 tonnes CO_2e per year. The net impact on carbon sequestration was an increase of 6% overall; with the largest impacts on the more extensive beef and sheep farms (4.5% and 17% respectively) and a much smaller impact on the dairy and mixed farms (1.4% and 2.5%) because of their lower proportion of permanent grassland.

Table 3.3.5. *Net impacts on farm GHG balance* – this scheme option has a slightly greater impact on GHG emissions than on C-sequestration. Overall farm C-sequestration increased from 35% of farm emissions to 43% of farm emissions (21% to 25% without the leveraging effect of sheep farm 1).

3.3.2 Grazing Management of Open Country

The Open Country management option could be applied to 10 of the 15 farms (beef farms 1,3,4 and 5; dairy farms 1 and 3; mixed farm 3 and sheep farms 2,3 and 4). Applying the option reduced sheep stocking rates but not cattle stocking rates, as the land entering this option is generally grazed by sheep rather than cattle (and certainly not dairy cattle).

Table 5.4.1. *Changes in livestock numbers* – Sheep numbers reduced by 13% overall; with smaller reductions where sheep were the secondary enterprise (beef farms 7%, dairy farms 14%). The impact of the option was greatest on sheep-only farms where stock reductions averaged 23%. Reducing livestock numbers has a consequential effect on modelled productivity, with lamb sales down by an average of 5% (22% on dairy farms – only one of which produces lamb – and 19% on sheep farms).

Table 5.4.1 and 5.4.2. *Changes in GHG emissions* – the modelling links changes in animal numbers to farm inputs such as feed purchases as well as 'downstream' emissions from soils and the livestock itself. Overall, GHG emissions for the 10 farms on which this option was applied reduced by an average of 5%, or 24 metric tonnes of CO_2 equivalent per annum. The changes were distributed across farm inputs such as feed and fertiliser purchases (-1%), embodied GHG in imported livestock (-7%), N_2O emissions from manure, excreta and soils (-2%) and methane emissions (-3%). Similarly to the Zero N option, these reductions to inputs and bought-in stock will impact on the markets and producers of youngstock, extending the influence of the scheme option beyond the boundaries of the participating farm.

Changes in C sequestration – this scheme option result in no modellable effect on C sequestration, since no land management change was applied. No studies could be found to support any assumptions about changes in sequestration rates in upland soils caused by small changes in stock densities.

Table 5.4.3. *Net impacts on farm GHG balance* – overall, this option reduced GHG emissions but had no modellable effect on C sequestration. On the farms where this option applied, net impact was an increase in farm C-sequestration from 26% to 28% of farm emissions. On the sheep farms where this option had the most effect, C-sequestration increased from 48% to 55% of farm GHG emissions.

3.3.3 Woodland margin extension

Extending the woodland margin increases woodland area at the expense of grassland – which constitutes a land-use change as well as reducing farmed land area and therefore stock carrying capacity and inputs associated with livestock and land management. This option could be applied to only four of the 15 farms (beef farms 1 and 2, dairy farm 3 and sheep farm 4).

Table 5.5.1. *Changes in N use and livestock numbers* – The land area converted from grassland to woodland was very small. Modelled nitrogen reductions averaged 1.5% and livestock were reduced by only about 1%. Reducing livestock numbers has a consequential effect on modelled productivity, with meat sales down by 0.5% and milk by 3.8%.

Table 5.5.1. *Changes in GHG emissions* – the modelling links changes in animal numbers to farm inputs such as feed purchases as well as 'downstream' emissions from soils and the livestock itself. Overall, GHG emissions for the five farms reduced by an average of 1.5%, or 23 metric tonnes of CO_2 equivalent per annum. The changes were distributed across farm inputs such as feed and fertiliser purchases (-0.02%), N_2O emissions from manure, excreta and soils (-0.1%), methane emissions (-0.3%) and CO_2 from lime application (-1.6%).

Table 5.5.2. *Changes in C sequestration* – this scheme option affected C sequestration through the effects of land-use change, increased woodland area and decreased soil area under grassland. Land-

use change C sequestration on the farms was very small in the baseline assessments, and increased by 0.06%. The net impact on carbon sequestration was an increase of 0.03% overall; with the largest impacts on farms with the most woodland margin (beef farm 2 sequestration increased by 0.08%). The decrease in sequestration under grassland (-0.07%) was more than offset by the increase in woodland sequestration (+3%). The modelled conversion of grassland to woodland has a net positive impact on C storage although the farm impacts are small because woodland boundary length (ie applicable land area for this option) on most farms is small.

Table 5.5.3. *Net impacts on farm GHG balance* – this scheme option has a slightly greater impact on GHG emissions than on C-sequestration. Overall farm C-sequestration across the participating farms increased from 26% to 27% of farm emissions.

3.3.4 Create New Streamside Corridor – Both Sides / Tree Planting

Planting woodland on the riparian margin (Streamside Corridor) increases woodland area at the expense of grassland – which constitutes a land-use change as well as reducing farmed land area and therefore stock carrying capacity and inputs associated with livestock and land management. This option could be applied to only five of the 15 farms (beef farm 2, dairy farm 3, mixed farms 2 and 3 and sheep farm 2).

Table 5.6.1. *Changes in N use and livestock numbers* – The land area converted from grassland to woodland was very small. Nitrogen reductions modelled were less than 0.5% and livestock were reduced by only 0.02%. Reducing livestock numbers has a consequential effect on modelled productivity, with meat sales down by 0.02% and milk by 0.05%.

Table 5.6.2. *Changes in GHG emissions* – the modelling links changes in animal numbers to farm inputs such as feed purchases as well as ‘downstream’ emissions from soils and the livestock itself. Overall, GHG emissions for the five farms reduced by an average of 0.11%, or 1.4 metric tonnes of CO_2 equivalent per annum. The changes were distributed across farm inputs such as feed and fertiliser purchases (-0.03%), N_2O emissions from manure, excreta and soils (-0.03%), methane emissions (-0.04%) and CO_2 from lime application (-0.4%).

Table 5.6.3 and 5.6.4. *Changes in C sequestration* – this scheme option affected C sequestration through the effects of land-use change, increased woodland area and decreased soil area under grassland. Land-use change C sequestration on the farms was very small in the baseline assessments, and increased by 6% or 3 tonnes CO_2e per year. The net impact on carbon sequestration was an increase of 0.5% overall; with the largest impacts on farms with the most river margin (sheep farm 2 sequestration increased by 1.6%). The decrease in sequestration under grassland (-0.5%) was more than offset by the increase in woodland sequestration (+2.3%). The modelled conversion of grassland to woodland has a net positive impact on C storage although the farm impacts are small because riparian boundary length (ie applicable land area for this option) on most farms is small.

Table 5.6.5. *Net impacts on farm GHG balance* – this scheme option has a slightly greater impact on C-sequestration than on GHG emissions. Overall farm C-sequestration increased from 22% to 23% of farm emissions.

3.4 Discussion

On this set of virtual farms, the Glastir measures applied had the intended effect of reducing modelled GHG emissions and (in most cases) increasing modelled C-sequestration in biomass and soils. The net impact of these changes was generally relatively small, either because the land areas on which options were applied represented a small proportion of farm area, or the management changes applied were subtle. The most effective option was "no inputs to grazed permanent pasture", where farm GHG emissions reduced by an average of 7% and C sequestration increased by 6%. Over time, the annual impact of this C sequestration increase will fall, as the soil and grassland vegetation adjust to the changed N regime. IPCC guidelines and Jones and Emmett (2009) recommend that land-use change is modelled as an annually declining impact over a period of several years.

The effectiveness of the different options in reducing GHG and increasing C sequestration varied between farm types. This is partly a function of farm types being associated with different bio-geographical environments – sheep tend to be produced on farms at higher altitude with greater access to open country upland grazing; dairy farms are generally in lowland areas with a very high proportion of flatter land under intensive improved grassland or arable / cut forage management. This effect was most obvious in the "Grazing management of Open Country" option, where farms of all four broad types could take advantage of the option but its impacts varied widely. The overall average of 5% GHG reduction was not representative of impacts on different farm types – with a 14% reduction on sheep farms, 2% reduction on dairy farms (where sheep are primarily used as a tool for grazing quality management) and 1% reduction on farms where the main enterprise is beef cattle.

GHG reductions were mediated primarily through reductions in livestock, with small additional reductions associated with lower requirements for farm inputs associated with stock management. These reductions to inputs extend the impact of the scheme option beyond the boundaries of the participating farm, and into the upstream agricultural supply chain. Impacts on the wider supply chain might be positive or negative, and are difficult to predict with confidence. In the context of the Welsh national GHG budget and national food security, such changes are likely to decrease imports of fertilisers and protein feeds (primarily soya), and reduce demand of replacement livestock (extending the option impact to non-participating livestock producers). However, reduced supply of livestock products may be compensated by increasing food imports if national demand remains constant. A further complication is farmer behaviour: informal observations suggest that under previous agri-environment schemes apparent grazing-pressure livestock reductions have been produced by increasing stock movements (e.g. tack grazing outside the farm boundary, region or even English farms).

Reductions in livestock numbers may or may not lead to reductions in farm productivity and hence the economic and supply performance of the farm. The precise impacts of livestock reductions are difficult to predict, since reducing grazing pressure may induce a range of changes from vegetation change ('scrubbing up' requiring mechanical management and hence increasing fuel use etc.) to increased forage availability and therefore improved livestock quality, fertility and output per head (more finished lambs per ewe).

The conversion of grassland to woodland results in a net increase in carbon sequestration but the effectiveness of the “woodland margin extension” and “streamside corridor” options is limited by the small number of farms with applicable land. Although an effort was made to ensure that some of the farms selected would be able to apply this option, few farms have woodland or river margins within the farm boundary. If this option were also applied to farms with adjacent rivers or woodland (even if held by a different landowner) its applicability and impact might be greatly increased.

3.5 Conclusions

- On this set of virtual farms, the Glastir measures modelled had the intended effect of reducing GHG emissions and (in most cases) increasing C-sequestration in biomass and soils.
- The effectiveness of the different options in reducing GHG and increasing C sequestration varied between farm types
- GHG reductions were mediated primarily through reductions in livestock, with small additional reductions associated with lower requirements for farm inputs associated with stock management. These reductions to inputs extend the impact of the scheme option beyond the boundaries of the participating farm, and into the upstream agricultural supply chain.
- Reductions in livestock numbers may or may not lead to reductions in farm productivity and hence the economic and supply performance of the farm, although this is difficult to predict with confidence.
- The conversion of grassland to woodland results in a net increase in carbon sequestration but the effectiveness of the “woodland margin extension” and “streamside corridor” options is limited by the small number of farms with applicable land.

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Table 3.2.1. Baseline **farm year total GHG** emissions data for the 15 test farms. Bold, italic numbers represent group average contribution to the overall GHG emissions total.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Total annual GHG emissions kg CO_2e	GHG annual emissions breakdown (kg CO_2e per farm year): Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources	CO_2 from lime application	NET GHG from land use change
BEEF	1	460	168	350	**2,737,627**	218,127	1,132,134	444,889	716,393	91,675	114,848
	2	96	10	290	**418,983**	40,364	0	83,610	290,227	3,667	-36
	3	279	64	240	**2,361,458**	600,892	5,489	554,248	1,097,108	96,259	0
	4	140	0	220	**992,016**	165,915	19,999	288,703	512,329	5,066	0
	5	90	0	70	**1,964,612**	158,339	1,453,612	128,977	175,932	45,838	1,915
						13.6%	***23.5%***	***19.1%***	***40.5%***	***2.2%***	***0.9%***
DAIRY	1	70	42	266	**843,609**	272,511	0	177,247	385,392	3,575	0
	2	188	0	125	**2,188,313**	430,259	0	442,629	1,303,962	11,459	0
	3	182	1	100	**2,503,118**	947,137	52,069	515,905	962,866	25,000	0
	4	340	0	50	**2,564,250**	827,274	21,028	504,272	1,163,444	48,221	0
						30.5%	***0.7%***	***20.4%***	***47.3%***	***1.0%***	***0.0%***
MIXED	1	158	0	215	**1,272,893**	362,056	14,294	248,198	620,843	27,503	0
	2	214	0	175	**2,261,067**	562,089	0	454,500	1,198,640	45,838	-302
	3	108	0	60	**689,560**	126,096	34,259	174,951	353,505	742	-72
						23.9%	***2.0%***	***21.7%***	***51.0%***	***1.4%***	***0.0%***
SHEEP	1	117	40	310	**66,049**	15,272	0	23,098	22,973	0	0
	2	39	10	300	**72,486**	16,444	553	15,912	38,472	0	0
	3	143	68	100	**355,790**	52,818	11,664	114,377	169,082	0	0
	4	69	0	60	**130,080**	13,728	0	51,885	64,467	0	-108
						17.8%	***1.0%***	***32.2%***	***46.2%***	***0.0%***	***0.0%***

Table 3.2.2. Baseline GHG emissions **per-ha** for the 15 test farms. Bold, italic numbers represent group average contribution to the overall GHG emissions total.

						GHG annual emissions breakdown (kg CO_2e per farm year)					
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**Total annual GHG emissions kg CO_2e per ha**	Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources	CO_2 from lime application	NET GHG from land use change
BEEF	1	460	168	350	**5,951**	474	2,461	967	1,557	199	250
	2	96	10	290	**4,368**	421	-	872	3,026	38	- 0
	3	279	64	240	**8,464**	2,154	20	1,987	3,932	345	-
	4	140	0	220	**7,072**	1,183	143	2,058	3,652	36	-
	5	90	0	70	**21,829**	1,759	16,151	1,433	1,955	509	21
						13.6%	***23.5%***	***19.1%***	***40.5%***	***2.2%***	***0.9%***
DAIRY	1	70	42	266	**12,052**	3,893	-	2,532	5,506	51	-
	2	188	0	125	**11,635**	2,288	-	2,353	6,933	61	-
	3	182	1	100	**13,726**	5,194	286	2,829	5,280	137	-
	4	340	0	50	**7,534**	2,431	62	1,482	3,418	142	-
						30.5%	***0.7%***	***20.4%***	***47.3%***	***1.0%***	***0.0%***
MIXED	1	158	0	215	**8,076**	2,297	91	1,575	3,939	174	-
	2	214	0	175	**10,542**	2,621	-	2,119	5,588	214	- 1
	3	108	0	60	**6,385**	1,168	317	1,620	3,273	7	- 1
						23.9%	***2.0%***	***21.7%***	***51.0%***	***1.4%***	***0.0%***
SHEEP	1	117	40	310	**563**	130	-	197	196	-	-
	2	39	10	300	**1,859**	422	14	408	986	-	-
	3	143	68	100	**2,488**	369	82	800	1,182	-	-
	4	69	0	60	**1,885**	199	-	752	934	-	- 2
						17.8%	***1.0%***	***32.2%***	***46.2%***	***0.0%***	***0.0%***

Table 3.2.3. Baseline **farm-year total** carbon sequestration data for the 15 test farms. Bold, italic numbers represent group average contribution to the overall carbon sequestration total.

					GHG (carbon) sequestration breakdown (kg CO_2e per farm year)							
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**Total annual GHG emissions**	NET GHG from land use change	**Total annual C sequestration**	Woodland	Other trees	Hedgerows	Soils under grassland	Soils under wetlands
BEEF	1	460	168	350	**2,737,627**	114848	**434,125**	7165	32352	25220	365615	513
	2	96	10	290	**418,983**	-36	**80,589**	7840	207	3767	66438	2337
	3	279	64	240	**2,361,458**	0	**204,105**	0	0	0	204105	0
	4	140	0	220	**992,016**	0	**412,123**	32312	224244	51464	100663	0
	5	90	0	70	**1,964,612**	1915	**122,491**	45457	41	9075	67866	52
						0.9%	***18.3%***	***11.3%***	***12.4%***	***6.1%***	***69.3%***	***0.6%***
DAIRY	1	70	42	266	**843,609**	0	**124,846**	2925	62	0	61764	0
	2	188	0	125	**2,188,313**	0	**192,830**	22634	135	17675	152179	208
	3	182	1	100	**2,503,118**	0	**399,434**	123827	25337	70777	139743	779
	4	340	0	50	**2,564,250**	0	**206,221**	17310	550	10263	177892	207
						0.0%	***11.9%***	***13.4%***	***1.7%***	***8.0%***	***62.4%***	***0.1%***
MIXED	1	158	0	215	**1,272,893**	0	**152,699**	12198	930	15043	123901	0
	2	214	0	175	**2,261,067**	-302	**136,381**	11515	70	6408	118241	0
	3	108	0	60	**689,560**	-72	**98,330**	21125	0	0	77205	0
						0.0%	***10.8%***	***12.6%***	***0.2%***	***4.8%***	***82.1%***	***0.0%***
SHEEP	1	117	40	310	**66,049**	0	**165,042**	10034	2198	54776	96783	935
	2	39	10	300	**72,486**	0	**40,834**	3082	873	0	34070	26
	3	143	68	100	**355,790**	0	**117,161**	5811	10992	0	96702	2809
	4	69	0	60	**130,080**	-108	**69,500**	7458	0	1682	60344	0
						0.0%	***98.1%***	***7.3%***	***3.2%***	***8.9%***	***77.9%***	***0.8%***

Table 3.2.4. Baseline carbon sequestration **per ha** data for the 15 test farms. Bold, italic numbers represent group average contribution to the overall carbon sequestration total.

					GHG (carbon) sequestration breakdown (kg CO_2e per ha)							
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**Total annual GHG emissions per ha**	NET GHG from land use change	**Total annual C sequestration**	Woodland	Other trees	Hedgerows	Soils under grassland	Soils under wetlands
BEEF	1	460	168	350	**5,951**	250	**944**	16	70	55	795	1
	2	96	10	290	**4,368**	- 0	**840**	82	2	39	693	24
	3	279	64	240	**8,464**	-	**732**	-	-	-	732	-
	4	140	0	220	**7,072**	-	**2,902**	230	1,599	367	718	-
	5	90	0	70	**21,829**	21	**1,361**	505	0	101	754	1
						0.9%	***18.2%***	***11.3%***	***12.6%***	***6.1%***	***69.4%***	***0.6%***
DAIRY	1	70	42	266	**12,052**	-	**1,784**	42	1	-	882	-
	2	188	0	125	**11,635**	-	**1,025**	120	1	94	809	1
	3	182	1	100	**13,726**	-	**2,190**	679	139	388	766	4
	4	340	0	50	**7,534**	-	**606**	51	2	30	523	1
						0.0%	***11.9%***	***13.4%***	***1.7%***	***8.0%***	***62.4%***	***0.1%***
MIXED	1	158	0	215	**8,076**	-	**969**	77	6	95	786	-
	2	214	0	175	**10,542**	- 1	**636**	54	0	30	551	-
	3	108	0	60	**6,385**	- 1	**910**	196	-	-	715	-
						0.0%	***10.8%***	***12.6%***	***0.2%***	***4.8%***	***82.1%***	***0.0%***
SHEEP	1	117	40	310	**563**	-	**1,406**	86	19	467	825	8
	2	39	10	300	**1,859**	-	**1,047**	79	22	-	874	1
	3	143	68	100	**2,488**	-	**819**	41	77	-	676	20
	4	69	0	60	**1,885**	- 2	**1,007**	108	-	24	875	-
						0.0%	***98.1%***	***7.3%***	***3.2%***	***8.9%***	***77.9%***	***0.8%***

Table 3.3.1. Changes in N input, livestock, production and farm-year total GHG emissions data for all farms with "No Inputs" option modelling applied. Bold, italic numbers represent group average contributions to the overall GHG emissions total. All GHG emissions values in kg CO_2e.

						Livestock change		Production change				GHG emissions change by farm source (kg CO_2e per farm year)					
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Change in N use (kg)	Sheep (head)	Cattle (head)	Lamb kg	Beef kg	Milk litre	**Change in total annual GHG emissions (kg CO_2e)**	Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from manure and excreta	N_2O from all sources	Methane from all sources	CO_2 from lime application
BEEF	1	460	168	350	-3,866	-189	-14	-4,332	-11,016	0	**-277,841**	-57,515	-90,571	-15,735	-46,995	-52,141	-30,619
	2	96	10	290	0		-14	0	0	0	**-34,863**	-1,166	0	-4,394	-7,324	-26,080	-293
	3	279	64	240	-2,491	-57	-42	0	-11,232	0	**-188,612**	-43,239	-439	-17,331	-42,943	-94,290	-7,701
	4	140	0	220	-855	-37	-22	-1,060	-1,615	0	**0**	0	0	0	0	0	0
	5	90	0	70	-480	-21	-6	-1,260	-8,494	0	**-154,321**	-9,981	-116,289	-5,092	-9,873	-14,511	-3,667
												-22,380	***-41,460***	***-8,510***	***-21,427***	***-37,404***	
DAIRY	1	70	42	266	-408	-32	-12	-630	0	-67,313	**-68,704**	-17,878	0	-7,808	-15,039	-35,500	-286
	2	188	0	125	-1,064		-56	0	-1,242	-190,000	**-196,840**	-24,652	0	-24,387	-41,887	-129,384	-917
	3	182	1	100	-2,987		-39	0	0	-168,356	**-170,696**	-21,480	-4,165	-19,527	-46,764	-96,287	-2,000
	4	340	0	50	-3,671		-49	0	0	-144,461	**-237,023**	-66,751	-2,103	-14,964	-47,002	-116,344	-4,822
												-32,690	***-1,567***	***-16,671***	***-37,673***	***-94,379***	
MIXED	1	158	0	215	0	-43	-20	-1,714	0	-74,000	**-104,241**	-23,796	-1,144	-12,281	-20,263	-56,838	-2,200
	2	214	0	175	-1,480		-26	0	-5,733	-115,475	**-191,675**	-31,722	0	-22,954	-41,835	-114,451	-3,667
	3	108	0	60	-748	-20	-6	-866	-1,386	-37,450	**-55,292**	-6,830	-2,741	-6,709	-13,474	-32,188	-59
												-20,783	***-1,295***	***-13,981***	***-25,190***	***-67,826***	
SHEEP	1	117	40	310	-167	-11	0	-193	0	0	**-5,006**	-1,461	0	-653	-2,167	-1,378	0
	2	39	10	300	0	-9	0	-173	0	0	**-3,039**	-834	-33	-558	-796	-1,376	0
	3	143	68	100	-176	-70	0	-903	0	0	**-19,816**	-2,479	-700	-3,732	-6,823	-9,814	0
	4	69	0	60	0	0	0	0	0	0	**0**	0	0	0	0	0	0
												-1,194	***-183***	***-1,236***	***-2,446***	***-3,142***	***0***

Table 3.3.2. Percentage changes in N input, livestock, production and GHG emissions data for all farms with "No Inputs" option modelling applied. Bold, italic numbers represent group average contributions to the overall GHG emissions. All GHG emissions values presented as % change from baseline.

						Livestock % change		Production % change				% GHG emissions change by farm source					
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	N use	Sheep	Cattle	Lamb	Beef	Milk	**Change in total annual GHG emissions**	Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from manure and excreta	N_2O from all sources	Methane from all sources	CO_2 from lime application
BEEF	1	460	68	100	-33	-6	-9	-6	-9		**-10**	-2%	-8	-1%	-2%	-2%	-33
	2	96	0	60			-9		0		**-8**	0%		-1%	-2%	-6%	-8
	3	279	0	0	-8	-6	-9	0	-9		**-8**	-2%	-8	-1%	-2%	-4%	-8
	4	140	168	350	-8	-6	-9	-6	-9		**0**	0%	0	0%	0%	0%	0
	5	90	10	290	-8	-6	-9	-6	-9		**-8**	-1%	-8	0%	-1%	-1%	-8
											-6%	***-1%***	***-6***	***-1%***	***-1%***	***-3%***	***-11***
DAIRY	1	70	64	240	-8	-6	-10	-6		-10	**-8**	-2%		-1%	-2%	-4%	-8
	2	188	0	220	-8		-10		-9	-10	**-9**	-1%		-1%	-2%	-6%	-8
	3	182	0	70	-8		-10			-10	**-7**	-1%	-8	-1%	-2%	-4%	-8
	4	340	42	266	-10		-10			-10	**-9**	-3%	-10	-1%	-2%	-5%	-10
											-8%	***-2%***	***-9***	***-1%***	***-2%***	***-5%***	***-9***
MIXED	1	158	0	125		-6	-10	-6		-10	**-8**	-2%	-8	-1%	-2%	-4%	-8
	2	214	1	100	-8		-10		-9	-10	**-8**	-1%		-1%	-2%	-5%	-8
	3	108	0	50	-8	-6	-10	-6	-9	-10	**-8**	-1%	-8	-1%	-2%	-5%	-8
											-8%	***-1%***	***-8***	***-1%***	***-2%***	***-5%***	***-8***
SHEEP	1	117	0	215	-33	-6		-6			**-8**	-2%		-1%	-3%	-2%	
	2	39	0	175		-5		-5			**-4**	-1%	-6	-1%	-1%	-2%	
	3	143	0	60	-6	-6		-6			**-6**	-1%	-6	-1%	-2%	-3%	
	4	69	40	310		0		0			**0**	0%		0%	0%	0%	
											-4%	***-1%***	***-6***	***-1%***	***-2%***	***-2%***	

Table 3.3.3. Changes in farm-year total carbon sequestration data for all farms with "No Inputs" option modelling applied. Bold, italic numbers represent group average contributions to the overall sequestration total. All carbon sequestration values in kg CO_2e.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Total annual GHG emissions kg CO_2e	Total annual GHG emissions per ha	Change in annual C sequestration (kgCO_2e) Total annual C sequestration	Total annual C sequestration kgCO_2e per ha	CO_2 in LAND-USE CHANGE
BEEF	1	460	168	350	**-277,841**	-604	60,667	132	60,667
	2	96	10	290	**-34,863**	-363	21,718	226	21,718
	3	279	64	240	**-188,612**	-676	53,667	192	53,667
	4	140	0	220	**0**	0	-	-	0
	5	90	0	70	**-154,321**	-1,715	18,289	203	18,289
							30,868	***151***	***30,868***
DAIRY	1	70	42	266	**-68,704**	-981	16,240	232	16,240
	2	188	0	125	**-196,840**	-1,047	29,178	155	29,178
	3	182	1	100	**-170,696**	-936	37,609	206	37,609
	4	340	0	50	**-237,023**	-696	18,885	55	18,885
							25,478	***162***	***25,478***
MIXED	1	158	0	215	**-104,241**	-661	32,667	207	32,667
	2	214	0	175	**-191,675**	-894	31,090	145	31,090
	3	108	0	60	**-55,292**	-512	20,300	188	20,300
							28,019	***180***	***28,019***
SHEEP	1	117	40	310	**-5,006**	-43	24,551	209	24,551
	2	39	10	300	**-3,039**	-78	12,600	323	12,600
	3	143	68	100	**-19,816**	-139	29,367	205	29,367
	4	69	0	60	**0**	0	-	-	0
							16,630	***184***	***16,630***

Table 3.3.4. Changes in carbon sequestration data for all farms with "No Inputs" option modelling applied. Bold, italic numbers represent group average contributions to the overall sequestration total. All carbon sequestration values presented as % change from baseline.

						% Change in annual C sequestration		
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**Total annual GHG emissions kg CO_2e**	**Total annual C sequestration**	**Total annual C sequestration $kgCO_2e$ per ha**	**CO_2 in LAND-USE CHANGE**
BEEF	1	460	68	100	**-10**	14%	14%	1,861
	2	96	0	60	**-8**	5%	5%	
	3	279	0	0	**-8**	2%	2%	
	4	140	168	350	**0**	0%	0%	0
	5	90	10	290	**-8**	1%	1%	
					-6.9%	***4.5%***	***4.5%***	***930%***
DAIRY	1	70	64	240	**-8**	4%		27
	2	188	0	220	**-9**	0%		
	3	182	0	70	**-7**	1%	1%	97
	4	340	42	266	**-9**	1%	1%	
					-8.3%	***1.4%***	***0.9%***	***62%***
MIXED	1	158	0	125	**-8**	3%	3%	5,210
	2	214	1	100	**-8**	1%	1%	21,164
	3	108	0	50	**-8**	4%	0	
					-8.2%	***2.5%***	***1.9%***	***13187%***
SHEEP	1	117	0	215	**-8**	0%		7,808
	2	39	0	175	**-4**	45%	45%	453
	3	143	0	60	**-6**	9%	9%	3,468
	4	69	40	310	**0**	16%	16%	0
					-4.3%	***17%***	***23%***	***2,932***

Table 3.3.5. Overall changes to GHG emissions, C sequestration and farm offset (kg CO_2e and % offset) for all farms where "No inputs" option modelling was applied. Bold, italic numbers represent group averages.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**Baseline Total annual GHG emissions kg CO_2e**	**Baseline Total annual C sequestration**	**Baseline Farm balance GHG emission**		**Zero N total annual GHG emissions kg CO_2e**	**Zero N total annual C sequestration**	**Zero N farm balance GHG emission**	
BEEF	1	460	168	350	2,737,627	434,125	2,303,501	16%	2459786	494792	1,964,994	20%
	2	96	10	290	418,983	80,589	338,394	19%	384120	102307	281,813	27%
	3	279	64	240	2,361,458	204,105	2,157,353	9%	2172846	257772	1,915,074	12%
	4	140	0	220	992,016	412,123	579,893	42%	992016	412123	579,893	42%
	5	90	0	70	1,964,612	122,491	1,842,120	6%	1810291	140780	1,669,511	8%
								18%				***22%***
DAIRY	1	70	42	266	843,609	124,846	718,763	15%	774905	141086	633,819	18%
	2	188	0	125	2,188,313	192,830	1,995,483	9%	1991473	222008	1,769,465	11%
	3	182	1	100	2,503,118	399,434	2,103,684	16%	2332422	437043	1,895,379	19%
	4	340	0	50	2,564,250	206,221	2,358,030	8%	2327227	225106	2,102,121	10%
								12%				***14%***
MIXED	1	158	0	215	1,272,893	152,699	1,120,193	12%	1168652	185366	983,286	16%
	2	214	0	175	2,261,067	136,381	2,124,685	6%	2069392	167471	1,901,920	8%
	3	108	0	60	689,560	98,330	591,230	14%	634268	118630	515,637	19%
								11%				***14%***
SHEEP	1	117	40	310	66,049	165,042	**-98,993**	**250%**	61043	189593	**-128,550**	**311%**
	2	39	10	300	72,486	40,834	31,652	56%	69446	53434	16,012	77%
	3	143	68	100	355,790	117,161	238,629	33%	335975	146528	189,447	44%
	4	69	0	60	130,080	69,500	60,580	53%	130080	69500	60,580	53%
								98%				***121%***

Table 3.4.1. Changes in N input, livestock, production and farm-year total GHG emissions data for all farms with Open Country option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions total. All GHG emissions change values in kg CO_2e.

					Livestock change		Production change				Change in GHG by farm source						
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Sheep (head)	Cattle (head)	Lamb kg	Beef kg	Milk litre	**Change in total annual GHG emissions (kg CO_2e)**	CO_2e in agrochemicals	CO_2e in feeds	CO_2e in bedding	Embodied GHG in all farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources
BEEF	1*	460	168	350	-366	0	-6822	0	0	**-78,635**	-7	0	0	-7	0	-30,832	-47,796
	2	96	10	290													
	3*	279	64	240	-53	0	0	0	0	**-15,527**	-1	-106	-38	-146	-231	-6,972	-8,179
	4*	140	0	220	-73	0	-1793	0	0	**0**	0	0	0	0	0	0	0
	5*	90	0	70	-3	0	-186	0	0	**-1,595**	-1	0	0	-1	-825	-365	-404
											-2	***-27***	***-10***	***-38***	***-264***	***-9,542***	***-14,095***
DAIRY	1*	70	42	266	-149	0	-2293	0	0	**-38,131**	-9	-3,726	-10	-3,745	0	-13,317	-21,069
	2	188	0	125													
	3*	182	1	100	0	0	0	0	0	**0**	0	0	0	0	0	0	0
	4	340	0	50													
											-4	***-1,863***	***-5***	***-1,872***	***0***	***-6,659***	***-10,534***
MIXED	1	158	0	215													
	2	214	0	175													
	3*	108	0	60	0	0	0	0	0	**0**	0	0	0	0	0	0	0
											0	***0***	***0***	***0***	***0***	***0***	***0***
SHEEP	1	117	40	310													
	2*	39	10	300	-61	0	985	0	0	**-10,942**	0	3,963	0	3,963	158	-5,518	-9,546
	3*	143	68	100	-358	0	-3733	0	0	**-87,024**	-1	-4,389	-124	-4,632	-2,893	-29,535	-49,963
	4*	69	0	60	-17	0	-193	0	0	-4579	0	-228	-49	-278	0	-1,851	-2,450
											0	***-218***	***-58***	***-316***	***-912***	***-12,301***	***-20,653***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with upland or upland margin grazing land including rough grassland and unenclosed grassland.

Table 3.4.2. Changes in N input, livestock, production and GHG emissions data for all farms with Open Country option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions. All GHG emissions values in presented as % change from baseline.

					Livestock % change	Production % change		Change in GHG by farm source						
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Sheep	Lamb kg	**Total annual GHG emissions**	CO_2e in agrochemicals	CO_2e in feeds	CO_2e in bedding	Embodied GHG in all farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources
BEEF	1*	460	68	100	-12	-9	**-3**	-0.3	0.0		0.0%	0.0%	-1.1%	-1.7%
	2	96	0	60										
	3*	279	0	0	-6	0	**-1**	0.0	-0.1	-0.7	0.0%	-4.2%	-0.3%	-0.3%
	4*	140	168	350	-12	-10	**0**	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%
	5*	90	10	290	-1	-1	**0**	-0.9	0.0	0.0	0.0%	-0.1%	0.0%	0.0%
					-7	***-5***	***-0.9%***	***0%***	***0%***	***0%***	***0.0%***	***-1.1%***	***-0.4%***	***-0.5%***
DAIRY	1*	70	64	240	-28	-22	**-5**	-4.1	-2.0	-1.1	-0.4%		-1.6%	-1.3%
	2	188	0	220										
	3*	182	0	70	0		**0**	0.0	0.0	0.0	0.0%	0.0%	0.0%	-0.8%
	4	340	42	266										
					-14	***-22***	***-2.3%***	***-2%***	***-1%***	***-1%***	***-0.2%***	***0.0%***	***-0.8%***	***-1.1%***
MIXED	1	158	0	125										
	2	214	1	100										
	3*	108	0	50	0	0	**0**	0.0	0.0	0.0	0.0%	0.0%	0.0%	0.0%
					0	***0***	***0%***	***0.0***	***0.0***	***0.0***	***0.0%***	***0.0%***	***0.0%***	***0.0%***
SHEEP	1	117	0	215										
	2*	39	0	175	-35	-29	**-15**	-28.5	-28.5		-5.5%	-28.5%	-7.6%	-13.2%
	3*	143	0	60	-31	-25	**-24**	-0.5	-24.8	-24.8	-1.3%	-24.8%	-8.3%	-14.0%
	4*	69	40	310	-4	-4	**-4**	-3.6	-3.6	-3.6	-0.2%		-1.4%	-1.9%
					-23	***-19***	***-14.4%***	***-11%***	***-19%***	***-14%***	***-2.3%***	***-26.7%***	***-5.8%***	***-9.7%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with upland or upland margin grazing land including rough grassland and unenclosed grassland.

Table 3.4.3. Overall changes to GHG emissions, C sequestration and farm offset (kg CO_2e and % offset) for all farms where Open Country option modelling was applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group averages.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Baseline Total annual GHG emissions kg CO_2e	Baseline Total annual C sequestration	Baseline Farm balance GHG emission		Open Country total annual GHG emissions kg CO_2e	Open Country total annual C sequestration	Open Country farm balance GHG emission	
BEEF	1*	460	168	350	2,737,627	434,125	2,303,501	16%	2,658,992	434,125	2,224,866	16%
	2	96	10	290								
	3*	279	64	240	2,361,458	204,105	2,157,353	9%	2,345,931	204,105	2,141,826	9%
	4*	140	0	220	992,016	412,123	579,893	42%	992,016	412,123	579,893	42%
	5*	90	0	70	1,964,612	122,491	1,842,120	6%	1,963,017	122,491	1,840,526	6%
								18%				***18%***
DAIRY	1*	70	42	266	843,609	124,846	718,763	15%	805,478	124,846	680,632	15%
	2	188	0	125								
	3*	182	1	100	2,503,118	399,434	2,103,684	16%	2,503,118	399,434	2,103,684	16%
	4	340	0	50								
								15%				***16%***
MIXED	1	158	0	215								
	2	214	0	175								
	3*	108	0	60	689,560	98,330	591,230	14%	689,560	98,330	591,230	14%
								14%				***14%***
SHEEP	1	117	40	310								
	2*	39	10	300	72,486	40,834	31,652	56%	61,543	40,834	20,709	66%
	3*	143	68	100	355,790	117,161	238,629	33%	268,767	117,161	151,606	44%
	4*	69	0	60	130,080	69,500	60,580	53%	125,501	69,500	56,001	55%
								48%				***55%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with upland or upland margin grazing land including rough grassland and unenclosed grassland.

Table 3.5.1. Changes in N input, livestock, production and farm-year total GHG emissions data for all farms with Woodland Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions total. All GHG emissions change values in kg CO_2e.

						Livestock change		Production change				**Change in GHG by farm source (kg CO_2e)**				
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	N use	Sheep (head)	Cattle (head)	Lamb kg	Beef kg	Milk litre	**Change in total annual GHG emissions (kg CO_2e)**	Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources	CO_2 from lime application
BEEF	1*	460	168	350	-74	-15	-1	-348	-918	0	**-15,689**	-1,112	-7,280	-2435	-4273	-590
	2*	96	10	290	0	0	-3	0	0	0	**-7,280**	-273	0	-1521	-5418	-69
	3	279	64	240												
	4	140	0	220												
	5	90	0	70												
												-692	***-3,640***	***-1,978***	***-4,845***	***-329***
DAIRY	1	70	42	266												
	2	188	0	125												
	3*	182	1	100	-1419	0	-15	0	0	-63969	**-89,537**	-30,611	-1,978	-19412	-36585	-950
	4	340	0	50												
												-30,611	***-1,978***	***-19,412***	***-36,585***	***-950***
MIXED	1	158	0	215												
	2	214	0	175												
	3	108	0	60												
												0	***0***	***0***	***0***	***0***
SHEEP	1	117	40	310												
	2	39	10	300												
	3	143	68	100												
	4*	69	0	60	0	-8	0	-97	0	0	-2192	-140	0	-883	-1168	0
												-140	***0***	***-883***	***-1,168***	***0***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with areas of owned woodland adjacent to pasture.

Table 3.5.2. Changes in C sequestration data for all farms with Woodland Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions. All GHG emissions values presented as % change from baseline.

					% Change in GHG (carbon) sequestration breakdown				
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	**% Change in total annual C sequestration**	**% Change in annual C sequestration per ha**	Woodland	Land-use change	Soils under grassland
BEEF	1*	460	68	100	0.05%	0.05%	0.08%	0.19%	-0.03%
	2*	96	0	60	0.08%	0.43%	0.56%	0.00%	-0.14%
	3	279	0	0					
	4	140	168	350					
	5	90	10	290					
					0.07%	***0.24%***	***0.32%***	***0.09%***	***-0.08%***
DAIRY	1	70	64	240					
	2	188	0	220					
	3*	182	0	70	0.00%	0.48%	0.56%	0.05%	0.00%
	4	340	42	266					
					0.0%	***0.5%***	***0.6%***	***0.0%***	***0.0%***
MIXED	1	158	0	125					
	2	214	1	100					
	3	108	0	50					
					0%	***0%***	***0%***	***0%***	***0%***
SHEEP	1	117	0	215					
	2	39	0	175					
	3	143	0	60					
	4*	69	40	310	0.00%	1.00%	10.49%	0.01%	-0.13%
					0.00%	***1.00%***	***10.49%***	***0.01%***	***-0.13%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with areas of owned woodland adjacent to pasture.

Table 3.5.3. Overall changes to GHG emissions, C sequestration and farm offset (kg CO_2e and % offset) for all farms where Woodland Margin option modelling was applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group averages.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Baseline Total annual GHG emissions kg CO_2e	Baseline Total annual C sequestration	Baseline Farm balance GHG emission		Open Country total annual GHG emissions kg CO_2e	Open Country total annual C sequestration	Open Country farm balance GHG emission	
BEEF	1*	460	168	350	2,737,627	434,125	2,303,501	16%	2,658,992	434,125	2,224,866	16%
	2*	96	10	290	418,983	80,589	338,394	19%	418,983	80,589	338,394	19%
	3	279	64	240								
	4	140	0	220								
	5	90	0	70								
								18%				***18%***
DAIRY	1	70	42	266								
	2	188	0	125								
	3*	182	1	100	2,503,118	399,434	2,103,684	16%	2,503,118	399,434	2,103,684	16%
	4	340	0	50								
								16%				***16%***
MIXED	1	158	0	215								
	2	214	0	175								
	3	108	0	60								
SHEEP	1	117	40	310								
	2	39	10	300								
	3	143	68	100								
	4*	69	0	60	130,080	69,500	60,580	53%	125,501	69,500	56,001	55%
								53%				***55%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with areas of owned woodland adjacent to pasture.

Table 3.6.1. Changes in N input, livestock, production and farm-year total GHG emissions data for all farms with Riparian Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions total. All GHG emissions change values in kg CO_2e.

					fertilisers change (kg)			Livestock change		Production change				Change in GHG by farm source (kg CO_2e)				
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	N use	P use	K use	Sheep (head)	Cattle (head)	Beef kg	Milk litre	**Change in total annual GHG emissions (kg CO_2e)**	**Change in total annual GHG emissions (kg CO_2e) per ha**	Embodied GHG in farm inputs (excluding livestock purchases)	Embodied GHG in livestock purchases	N_2O from all sources	Methane from all sources	CO2 from lime application
BEEF	1	460	168	350														
	2*	96	10	290	0	0	0	0.0	0	0	0	**-801**	**-8**	-84	0	-147	-523	-47
	3	279	64	240														
	4	140	0	220														
	5	90	0	70														
														-84	***0***	***-147***	***-523***	***-47***
DAIRY	1	70	42	266														
	2	188	0	125														
	3*	182	1	100	-232	0	-22	0.0	0	0	-1567	**-4,850**	**-27**	-2,134	-48	-1616	-896	-155
	4	340	0	50														
														-2,134	***-48***	***-1,616***	***-896***	***-155***
MIXED	1	158	0	215														
	2*	214	0	175	-29	-2	-22	0.0	0	-14	-273	**-945**	**-4**	-350	0	-248	-275	-72
	3*	108	0	60	-23	-7	-8	-0.1	0	-5	-136	**-465**	**-4**	-170	-11	-164	-118	-2
														-260	***-6***	***-206***	***-196***	***-37***
SHEEP	1	117	40	310														
	2*	39	10	300	0	0	0	-0.1	0	0	0	**-30**	**-1**	-7	0	-8	-14	0
	3	143	68	100														
	4	69	0	60														
														-7	***0***	***-8***	***-14***	***0***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with river margins within the farm boundary and bordering pasture.

Table 3.6.2. Changes in N input, livestock, production and GHG emissions data for all farms with Riparian Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions total. All GHG emissions in % change from baseline.

					% change in fertiliser use			% Livestock change		% production change			**% change in GHG emissons**			
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	N use	P use	K use	Sheep	Cattle	Beef	Milk	**% Change in total annual GHG emissions**	Embodied GHG in farm inputs (excluding livestock purchases)	N_2O from all sources	Methane from all sources	CO_2 from lime application
BEEF	1	460	68	100												
	2*	96	0	60				0.0%	-0.2%	0.0%		**-0.19%**	-0.02%	-0.04%	-0.1%	-1.3%
	3	279	0	0												
	4	140	168	350												
	5	90	10	290												
													-0.02%	***-0.04%***	***-0.12%***	***-1.29%***
DAIRY	1	70	64	240												
	2	188	0	220												
	3*	182	0	70	-0.62		-0.62	0.00	-0.09		-0.09	**-0.19%**	-0.1%	-0.1%	0.0%	-0.6%
	4	340	42	266												
													-0.09%	***-0.06%***	***-0.04%***	***-0.62%***
MIXED	1	158	0	125												
	2*	214	1	100	-0.16	-0.16	-0.16	0.00	-0.02	-0.02	-0.02	**-0.04%**	-0.02%	-0.01%	-0.01%	-0.16%
	3*	108	0	50	-0.24	-0.24	-0.24	0.00	-0.04	-0.03	-0.04	**-0.07%**	-0.02%	-0.02%	-0.02%	-0.24%
													-0.02%	***-0.02%***	***-0.01%***	***-0.20%***
SHEEP	1	117	0	215												
	2*	39	0	175				-0.05	0.00			**-0.04%**	-0.01%	-0.01%	-0.02%	0.00%
	3	143	0	60												
	4	69	40	310												
													-0.01%	***-0.01%***	***-0.02%***	***0.00%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with river margins within the farm boundary and bordering pasture.

Table 3.6.3. Changes in N use, livestock, production and C sequestration data for all farms with Riparian Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions. All GHG emissions values presented in kg CO_2e per farm year.

					Change in fertiliser (kg)			Livestock change		Production change				Change in GHG (carbon) sequestration breakdown (kg CO_2e)		
Primary producer type		area (ha)	peat (ha)	Altitude (masl)	N use	P use	K use	Sheep (head)	Cattle (head)	Beef kg	Milk litre	**Change in total annual C sequestration (kg CO_2e)**	**Change in annual C sequestration per ha (kg CO_2e)**	Woodland	Land-use change	Soils under grassland
BEEF	1	460	168	350												
	2*	96	10	290	0	0	0	0.0	0	0	0	**2,023**	**21**	3035	53	-1065
	3	279	64	240												
	4	140	0	220												
	5	90	0	70												
												2,023	***21***	***3,035***	***53***	***-1,065***
DAIRY	1	70	42	266												
	2	188	0	125												
	3*	182	1	100	-232	0	-22	0.0	0	0	-1567	**6,161**	**34**	7004	44	-887
	4	340	0	50												
												6,161	***34***	***7,004***	***44***	***-887***
MIXED	1	158	0	215												
	2*	214	0	175	-29	-2	-22	0.0	0	-14	-273	**1,416**	**7**	1593	9	-186
	3*	108	0	60	-23	-7	-8	-0.1	0	-5	-136	**1,498**	**14**	1675	9	-186
												1,457	***10***	***1,634***	***9***	***-186***
SHEEP	1	117	40	310												
	2*	39	10	300	0	0	0	-0.1	0	0	0	**1,136**	**29**	1328	10	-202
	3	143	68	100												
	4	69	0	60												
												1,136	***29***	***1,328***	***10***	***-202***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with river margins within the farm boundary and bordering pasture.

Table 3.6.4. Changes in C sequestration data for all farms with Riparian Margin option modelling applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group average contributions to the overall GHG emissions. All GHG emissions values presented as % change from baseline.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Fertiliser % change			Livestock % change		Change in total annual C sequestration (%)	Change in annual C sequestration per ha (%)	% Change in GHG (carbon) sequestration breakdown		
					N use	P use	K use	Sheep	Cattle			Woodland	Land-use change	Soils under grassland
BEEF	1	460	68	100										
	2*	96	0	60				0.0	-0.2	0.5%	0%	4%		-1%
	3	279	0	0										
	4	140	168	350										
	5	90	10	290										
										0.5%	***0.5%***	***3.8%***	***0.0%***	***-1.3%***
DAIRY	1	70	64	240										
	2	188	0	220										
	3*	182	0	70	-0.6		-0.6	0.0	-0.1	0.2%	0.2%	1.8%	11.3%	-0.2%
	4	340	42	266										
										0.2%	***0.2%***	***1.8%***	***11.3%***	***-0.2%***
MIXED	1	158	0	125										
	2*	214	1	100	-0.2	-0.2	-0.2	0.0	0.0	0.1%	0.1%	1.2%	6.3%	-0.1%
	3*	108	0	50	-0.2	-0.2	-0.2	0.0	0.0	0.2%	0.2%	1.7%		-0.2%
										0.1%	***0.1%***	***1.4%***	***0.1%***	***-0.2%***
SHEEP	1	117	0	215										
	2*	39	0	175				-0.1	0.0	1.6%	1.6%	3.3%	0.4%	-0.5%
	3	143	0	60										
	4	69	40	310										
										1.6%	***1.6%***	***3.3%***	***0.4%***	***-0.5%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with river margins within the farm boundary and bordering pasture.

Table 3.6.5. Overall changes to GHG emissions, C sequestration and farm offset (kg CO_2e and % offset) for all farms where Riparian Margin option modelling was applied. Farm numbers with asterisks represent farms where the option was applicable. Bold, italic numbers represent group averages.

Primary producer type		area (ha)	peat (ha)	Altitude (masl)	Baseline Total annual GHG emissions kg CO_2e	Baseline Total annual C sequestration	Baseline Farm balance GHG emission		Riparian Margin total annual GHG emissions kg CO_2e	Riparian Margin total annual C sequestration	Riparian Margin farm balance GHG emission	
BEEF	1	460	168	350								
	2*	96	10	290	418,983	80,589	338,394	19%	418,182	82,612	335,570	20%
	3	279	64	240								
	4	140	0	220								
	5	90	0	70								
								19%				***20%***
DAIRY	1	70	42	266								
	2	188	0	125								
	3*	182	1	100	2,503,118	399,434	2,103,684	16%	2,498,269	405,594	2,092,674	16%
	4	340	0	50								
								16%				***16%***
MIXED	1	158	0	215								
	2*	214	0	175	2,261,067	136,381	2,124,685	6%	2,260,122	137,798	2,122,324	6%
	3*	108	0	60	689,560	98,330	591,230	14%	689,094	99,828	589,266	14%
								10%				***10%***
SHEEP	1	117	40	310								
	2*	39	10	300	72,486	40,834	31,652	56%	72,455	41,970	30,485	58%
	3	143	68	100								
	4	69	0	60								
								56%				***58%***

*Modelling was applied to farms where the Glastir option was applicable – in this case, farms with river margins within the farm boundary and bordering pasture.

Appendix 6.2

Application of the ECOSSE- model to estimate greenhouse gas and soil organic carbon fluxes and assessing the impacts of climate change on the gas fluxes from Wales

WP9

Final Report

Mohamed Abdalla, Mark Richards, Mark Pogson and Pete Smith

University of Aberdeen

Institute of Biological & Environmental Sciences, 23 St Machar Drive, AB24 3UU, Aberdeen, UK

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Summary

The Welsh government is committed to reduce greenhouse gas (GHG) and soil organic carbon (SOC) fluxes from agricultural systems and combat the effects of future climate change. In this study, the ECOSSE model was spatially applied to estimate GHG and SOC fluxes for Wales using Welsh soil data 2005 (NSRI, 2005) and UKCP09 climate data as inputs to the model. A land cover map (LCM2007) was applied and four major ecosystems (arable, grass, forest and natural) were investigated. The aims of the simulations were: 1) to estimate the annual net GHG fluxes from Wales; 2) to investigate the efficiency of the Glastir measure of reducing N fertilizer, on the net GHG fluxes, and 3) to investigate the effects of future climate change on the net GHG fluxes and net primary productivity (NPP). Nitrogen fertilizer was applied in the form of inorganic fertilizer (ammonium nitrate) and at a rate equal to the annual crop N demand. To investigate the effectiveness of the Glastir measure of reducing N fertilizer, fluxes of GHG and SOC at two reduced fertilizer application rates (80 and 60% of crop N demand) were compared to baseline (100% crop N demand). Three climate scenarios: baseline (1961-1990) and two future climate scenarios (2015-2050) low and high were studied. Results reveal that ECOSSE can credibly simulate GHG and SOC fluxes for Wales. However, the model underestimated CH_4 fluxes from saturated areas due to lack of observed spatial data on water table depth. The predicted annual net GHG flux for Wales at baseline (1961-1990) is 0.20 t CO_2e /ha/y which is equivalent to an annual C flux from the whole country of 0.37 Mt CO_2e /y. Reducing N fertilizer by 20% and 40% is efficient, and could reduce the overall average annual N_2O fluxes by 13 and 22%, respectively, and thereby reduce the net GHG fluxes. If the current N fertilizer application rate continues, future climate change by the year 2050 would not significantly affect the net GHG fluxes or NPP from Welsh soils. The difference between the two climate scenarios is, however, small (±2%). Our results demonstrate a robust basis to allow a much wider range of Glastir measures to be explored using the ECOSSE model (e.g. create 2- 3 meter wildlife corridor to include tree and shrub planting; establish a wildlife cover crop on improved land, and conversion from arable to grassland) though the model may need some modifications to do this.

1. Introduction

The Welsh Government is committed to reduce greenhouse gas (GHG) and soil organic carbon (SOC) fluxes from agriculture, protect the environment and combat the effects of future climate change. To achieve these objectives, the Glastir programme, in which farmers are adopting a range of on-farm measures to protect soil C, reduce GHG emissions, improve water quality and enhance biodiversity, is applied. This report gives a summary of ECOSSE-model simulation work to examine baseline emissions, quantify the impact of the Glastir measure of reducing N on GHG fluxes, shows the input data used to run the simulations and the spatial application of the model for Wales. The main aims of this work were: 1) to estimate the national annual average of GHG (CH_4 and N_2O) and SOC fluxes; 2) to investigate the effects of the low N Glastir measure on GHG and SOC fluxes; and 3) to investigate the effects of climate change on GHG and SOC fluxes. The ECOSSE spatial simulation covered four main ecosystems across Wales: (1) arable land (2) grassland (3) forestry and (4) natural land (i.e. dry heaths, abandoned grass, peat bogs and all semi-natural areas that are not designated as grass).

2. Methodologies

2.1 ECOSSE model

In this study, we applied the latest version of the ECOSSE (Estimation of Carbon in Organic Soils-Sequestration and Emissions; v. 5.0.1) model to estimate GHG and soil SOC fluxes across Wales. The ECOSSE model uses a pool type approach, and all of the major processes of C and N turnover in the soil are included and described using well-established equations driven by readily available input variables (Smith et al., 2010). ECOSSE can be used to carry out site-specific simulations with detailed input data, or spatial simulations using the limited data typically available at larger scales. Data describing SOC, soil water, plant inputs, nutrient applications and timing of management operations are used to run the model.

The water module in ECOSSE is based on SUNDIAL (Bradbury et al., 1993, Smith et al., 1996), where water streams through the soil pores as ‘piston flow’. The soils profile is divided into 5cm layers. Precipitation fills the uppermost soil layer with water until it reaches field capacity. Any remaining precipitation then fills the next layer to field capacity. This process is repeated until no precipitation remains or the bottom of the profile is reached. Water remaining after filling all layers to field capacity is partitioned between drainage (water leaving the soil profile), and excess, which fills layers to saturation from the bottom of the profile upwards. The ECOSSE model uses the observed depth of the water table, the available water at saturation and weather data to calculate the restriction to drainage (i.e. the fraction of the remaining water that becomes excess), that is required to achieve the observed water table depth. Addition or loss of C and N from different vegetation types are estimated using the C and N fractions in different parts of the plant, and harvest index for crops.

Potential evapotranspiration is calculated using the Thornthwaite equation (Thornthwaite, 1948). Total SOC and inert organic C amounts are added as inputs. The ECOSSE model then estimates the amount of organic matter (OM) input from plant material if information on plant yield is not provided. This is carried out using the amount of SOC as an input. The total SOC estimated by a steady-state (10,000 year) run using default plant inputs is compared to the total measured SOC, and a revised estimate is made of the OM inputs so that simulated steady state SOC matches the measured values. Plant material is divided into resistant and decomposable material, based on a decomposable plant material (DPM): resistant plant material (RPM) ratio of 1.44 (as used in the RothC model (Coleman and Jenkinson, 1996)).

The ECOSSE model simulates the soil profile up to 3 metres deep where the soil is divided into 5cm layers to facilitate the accurate simulation of processes to depth. During the decomposition process, material is exchanged between the soil organic matter (SOM) pools according to first-order rate equations, characterised by a specific rate constant for each pool. The rate constant of each pool is modified dependent on the temperature, water content, plant cover and pH of the soil (with additional modifiers dependent upon soil bulk density and inorganic N concentration in the case of anaerobic decomposition). The decomposition process results in gaseous losses of CO_2 and CH_4, with CO_2 losses dominating under aerobic conditions and CH_4 losses under anaerobic conditions. ECOSSE also simulates the oxidation of atmospheric CH_4, which, under aerobic conditions, can lead to the soil being a net consumer of CH_4.

The nitrogen (N) content of the soil follows the decomposition of the SOM, with a stable C: N ratio defined for each SOM pool at a given pH, and N being either mineralised or immobilised to maintain that ratio. Nitrogen is released from decomposing SOM as ammonium (NH_4^+) or nitrified to nitrate (NO_3^-). C and N may be lost from the soil by the processes of leaching (NO_3^-), dissolved organic C, and dissolved organic N, denitrification to nitric oxide (NO) and nitrous oxide (N_2O), volatilisation or crop off-take. C and N may be returned to the soil by plant inputs, inorganic fertilisers, atmospheric deposition or organic amendments (e.g. manure, crop residues). More details about the ECOSSE approach is found in Smith et al. (2010).

2.2 Spatial simulations

Application of the ECOSSE model to spatially simulate GHG and SOC fluxes was carried out for the whole Wales on a 1 km^2 soil grid basis. Grid simulations represent the 5 dominant soil types in each grid cell to capture soil heterogeneity at the sub-grid cell level. Each grid cell value in the model output represents the area-weighted mean of the simulations carried out for each soil type in the grid cell. The Land Cover Map (LCM2007; Morton et al., 2011) was applied, and four main ecosystems were simulated (arable, grassland, forest and natural). Rotational grassland is included in “arable land” in ECOSSE, as the grass ley phase forms part of a crop rotation.

ECOSSE is initialised before running each simulation, based on the assumption that the SOC in the soil column is at stable equilibrium under the initial land use at the start of the simulation. The model simulates physical fragmentation of soil organic matter resulting from cultivation by moving a proportion of the C and N in the humus pool, (which has a slow decomposition rate), to the decomposable and resistant plant material pools (which have faster decomposition rates). Redistribution of SOM during cultivation is simulated by homogenising the vertical distribution of the SOM pools down to the cultivation depth. For all ecosystems, the changes in GHG and SOC fluxes are calculated for the top metre of the soil profile. Only the top metre is considered because this is the depth to which soil parameters are provided by the soil database.

Results of N_2O, CH_4, SOC and net GHG balance were all reported in terms of CO_2-equivalent values (CO_2e) using the IPCC 100-year global warming potentials (GWPs) (IPCC, 2001). Net GHG flux is therefore referred to as net GHG balance throughout this report. Recent IPCC report (2013) has provided updated GWPs from those given in the IPCC 2001 report. However, for consistency and ease of comparisons with national GHG inventory, we have used the IPCC 2001 GWP values, where N_2O has a GWP of 296 and CH_4 has a GWP of 23 greater than CO_2 over an 100 year period (as these are used in all National GHG Inventories). Net GHG balance represents the combined impact of changes in N_2O, CH_4 and CO_2 from SOC change (expressed as CO_2e) and calculated as the sum of N_2O and CH_4 fluxes, minus the change in SOC (as CO_2). A positive net GHG balance is harmful and a negative net GHG balance is beneficial, discounting all other factors.

2.2.1 Soil data

Welsh soil data (NSRI, 2005) were used to provide initial soil conditions in the model. The data set provides soil data to a depth of 1 metre at a resolution of 1 km for the dominant soil types in each grid cell. The soil properties used from this database to drive the ECOSSE model were: organic C content, bulk density, pH, and sand, silt and clay faction. However, the Welsh data do not include information on the water-holding capacities of soils, so these were estimated using British Soil Survey pedotransfer functions (Hutson and Cass, 1987), which performed well in evaluations (Donatelli et al, 1996; Givi et al, 2004). The soil data also provide the percentage of each grid cell area covered by each soil type. The percentage cover is applied to the ECOSSE results for each dominant soil type in each grid cell to produce area-weighted grid cell mean responses.

2.3.2 Climate data

As input data, the ECOSSE model requires precipitation and air temperature to drive the soil water model and to determine temperature-based rate modifiers of various soil processes. The meteorological data were taken from the Spatially Coherent Projections (Murphy et al, 2009). UKCP09 provides, for high and low emissions scenarios, average monthly temperature and precipitation for Wales on a 25 km UKCP09rotated pole grid for overlapping 30-year periods centred upon decades ranging from the 2020s to the 2080s; the data were reprojected to the British National Grid for compatibility with other data in ECOSSE.

To investigate the effects of climate change on GHG and SOC fluxes, two climate scenarios (high and low emission scenarios) for a 35-year period running from 2015 to 2050 were applied and compared to the baseline climate scenario (1961-1990). The UKCP09 low and high emission climate scenarios correspond to the B1 and A1F1 emission scenarios of the IPCC (2007). See Appendix 1.

2.3.3 Yield data

In order to estimate the monthly plant inputs to the soil, the ECOSSE model requires yield data for each land use type. Yield data for the different arable crops have been obtained from EUROSTAT, whilst biomass data for other ecosystems were estimated using the Miami model (Lieth, 1975). Miami is an empirical net primary production (NPP) model that estimates annual net primary production from mean annual temperature and precipitation. The Miami estimate of net primary production was calculated for each decade in each grid cell using the same UKCP09 meteorological data and Welsh soil data, and was used to modify the equilibrium soil carbon inputs via changes in NPP over time.

2.3.4 Fertilizer application

Nitrogen fertilizer was applied in the form of inorganic fertilizer (ammonium nitrate) and at a rate equal to the annual crop N demand. Ammonium nitrate is assumed for N fertilizer because it is the most widely used form of fertilizer in the UK. Across all crops and grass in Great Britain in 2012 ammonium nitrate represented 39.6% of total fertilizer product used, whereas urea was represented only 7.3% (see the link: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/192605/fertiliseruse-report2012-25apr13.pdf). Crop N demand is a function of plant yield and the C: N ratio of the plant. Full fertilisation level (100%) meets 100% of the annual crop N demand whilst, 80% and 60% fertilisation levels meet only 80% and 60% of the annual crop N demand, without affecting yield in the model. It is assumed that crop yield would not be affected and that N fertilizer reductions could be achieved through efficiency improvements (better application rate, timing and placement). If crop yields were affected, N reduction would not be a viable option. The arable and grass lands are assumed to be fertilised whilst the forest and natural lands are assumed to remain unfertilised. The annual full N fertilizer application rate (for the grass and arable lands) estimated by ECOSSE was later back-calculated using the N_2O flux values and an emission factor of 1% (IPCC, 2006).

3. Results

3.1 Estimated present GHG and SOC fluxes in Wales

Figures 1 and 2 show the predicted mean annual GHG and SOC fluxes under baseline climate (1961-1990) for Wales. Fluxes of GHG and SOC were variable, depending on the ecosystem investigated. These variations in GHG and SOC fluxes resulted in variations in the amount of net GHG balance (+ve net GHG balance is detrimental and -ve net GHG balance is beneficial) between the different ecosystems as shown in Table 1. For all ecosystems, N_2O fluxes were the highest and major contributor to the net GHG balance especially for the grass and arable ecosystems, where N fertilizer was applied. However, fluxes of N_2O from the forest and natural ecosystems were low and contributed less to net GHG balance compared with that from the grass and arable ecosystems (Table 1 and Appendix 2). The overall annual average of N_2O fluxes from Wales is 0.2 t CO_2e /ha/y. For all ecosystems, fluxes of CH_4 were very low and represent a small sink for atmospheric C. The overall annual average uptake of CH_4 is 0.014 t CO_2e /ha/y (Table 1 and Appendix 3) though this value was probably underestimated by the ECOSSE model due to the absence of measured water table input data. Likewise, the fluxes of SOC were a minor sink with an overall average C uptake of 0.013 t CO_2e /ha/y. The overall average net GHG balance combining all gas fluxes is 0.198 t CO_2e /ha/y. This is equivalent to an annual C loss to the atmosphere of 54 kg C /ha/y. The highest emitting ecosystems are grass and arable, with net GHG balance of 0.449 and 0.205 t CO_2e/ha/y, respectively. The net fluxes from the forest (0.053 t CO_2e /ha/y) and natural (0.086 t CO_2e /ha/y) ecosystems are relatively small compared with that from the grass and arable ecosystems. Considering the net GHG balance of 0.199 t CO_2e /ha/y and the Welsh land use area of 1857690 ha (NS, 2004) the calculated annual fluxes for the whole of Wales at baseline climate (1961-1990) is 0.37 Mt CO_2e /y. As mentioned earlier, ECOSSE estimated N fertilizer depending on the crop N demand. However, back calculating the annual amount of this ECOSSE estimated N fertilizer using our N_2O flux values resulted in an equivalent value of 137 kg N /ha/y for the grass and arable lands.

Table 1: ECOSSE estimated mean annual GHG (N_2O and CH_4), SOC fluxes and net GHG balance (t CO_2e /ha/y*) at baseline climate 1961-1990, for Wales.

Ecosystem	N_2O	CH_4	SOC	Net GHG balance
Grassland	0.441	-0.014	-0.022	0.449
Arable land	0.200	-0.002	-0.007	0.205
Forest	0.050	-0.007	-0.010	0.053
Natural	0.108	-0.035	-0.013	0.086
Average	0.200	-0.014	-0.013	0.199

***** Where GWP for N_2O is 296 and for CH_4 is 23 times greater than CO_2 over a 100 year period.

3.2 Effects of the Glastir measure of reducing nitrogen on GHG and SOC fluxes in Wales

Figures 3 and 4 show the predicted annual N_2O and GHG fluxes from the grass and arable ecosystems at baseline (100% crop N demand) compared to two reduced fertilizer application rate scenarios (80% and 60% crop N demand) for Wales. Application of N fertilizer at 100% crop N demand resulted in higher N_2O fluxes and thereby, higher net GHG fluxes from soils (Table 2). However, application of reduced fertilization rates resulted in low N_2O fluxes and consequently low net GHG fluxes as shown in Figures 3 and 4. Reducing applied N fertilizer by 20% reduced annual N_2O fluxes from 0.44 to 0.37 t CO_2e /ha/y (-16%) and from 0.20 to 0.16 t CO_2e /ha/y (-20%) for the grass and arable lands, respectively. However, reducing applied N fertilizer by 40% resulted in reduced annual N_2O fluxes from 0.44 to 0.32 t CO_2e /ha/y (-27%) for the grassland and from 0.20 to 0.14 t CO_2e /ha/y (-30%) for arable land (Table 2). The overall annual N_2O fluxes, from all ecosystems, reduced from 0.20 to 0.18 (-13%) and 0.16 (-22%) t CO_2e /ha/y for 20% and 40% N fertilizer reductions, respectively. Consequently, the annual net GHG balance reduced from 0.20 to 0.17 (for 20% reduction) and 0.15 (for 40% N reduction) t CO_2e /ha/y (Table 2). This is equivalent to annual reductions in C loss of 7 and 12 kg C /ha/y for the 20% and 40% N fertilizer reductions, respectively, compared to the baseline (application of 100% crop N demand). The CH_4 production and SOC fluxes were not affected by reducing N fertilizer application rate.

Nevertheless, the amounts of net CH_4 and SOC fluxes, at all fertilisation scenarios, represented small sinks of 0.014 and 0.013 t CO_2e /ha/y, respectively, (Table 2 and Appendices 4 and 5).

Table 2: ECOSSE estimated changes in annual GHG (N_2O and CH_4), SOC fluxes and net GHG balance (t CO_2e/ ha/y*) due to reduced N fertilization rate in Wales.

Scenario	N_2O	CH_4	SOC	Net GHG balance
Baseline	0.200	-0.014	-0.013	0.199
20% fertilizer N reduction	0.175	-0.014	-0.013	0.173
40% fertilizer N reduction	0.156	-0.014	-0.013	0.154

***** Where GWP for N_2O is 296 and for CH_4 is 23 times greater than CO_2 over a 100 year period.

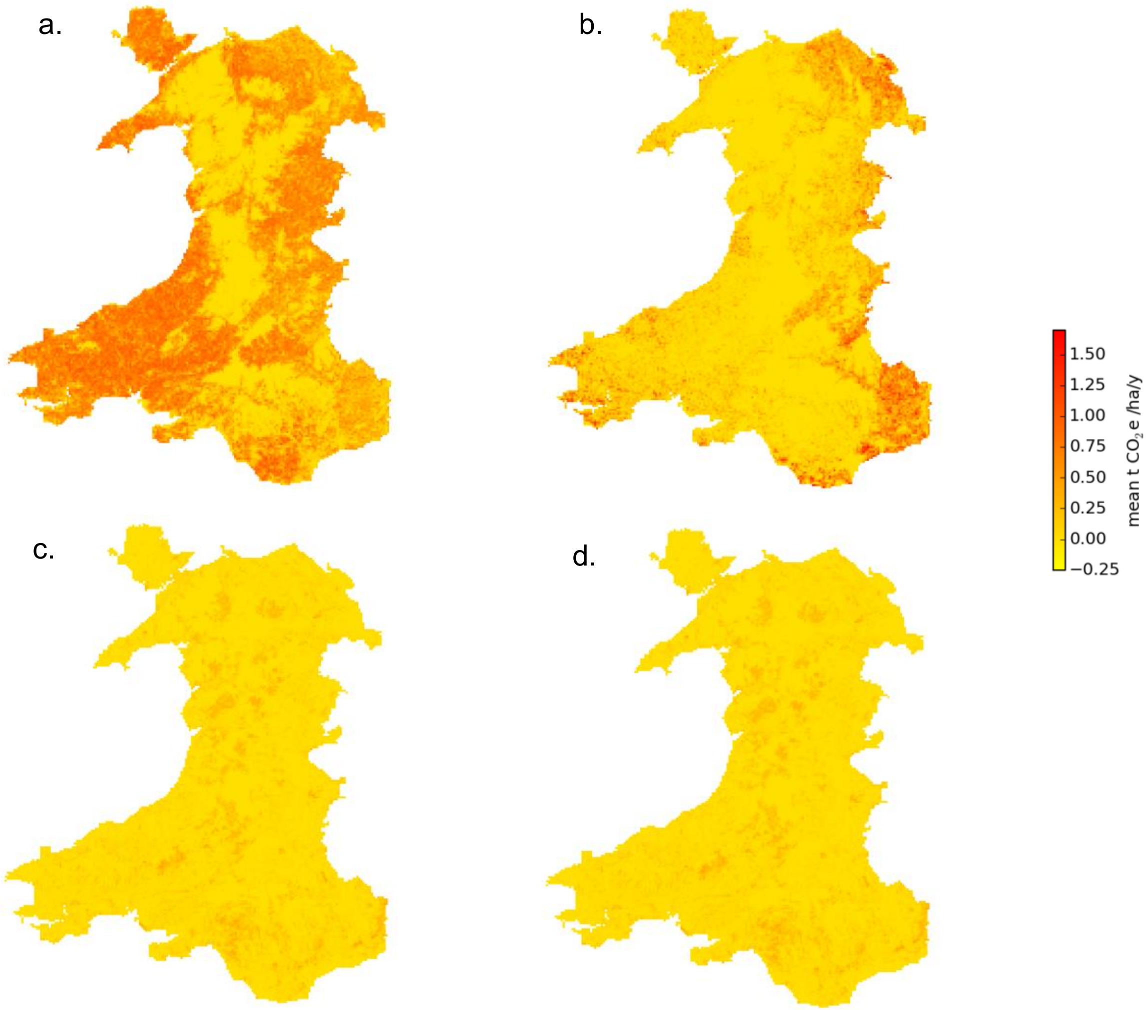

Figure 1: ECOSSE estimated mean annual net GHG fluxes (t CO_2e /ha/y) from the Welsh grassland (a), arable land (b), forest (c) and natural ecosystem (d), at baseline climate (1961-1990).

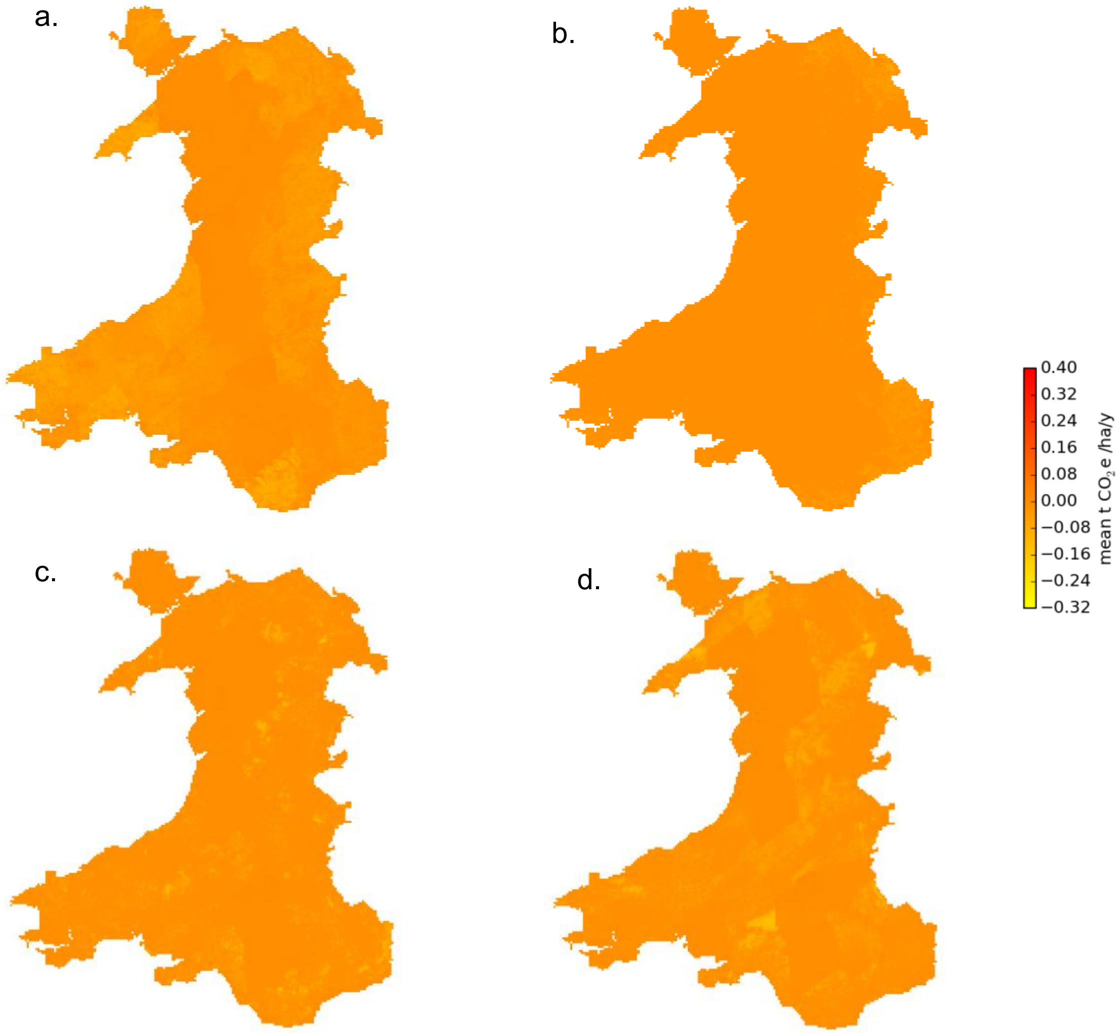

Figure 2: ECOSSE estimated mean annual SOC fluxes (t CO_2e /ha/y) from the Welsh grassland (a), arable land (b), forestry (c) and natural ecosystems (d), at baseline climate 1961-1990. (-ve sign means C sequestration in soils).

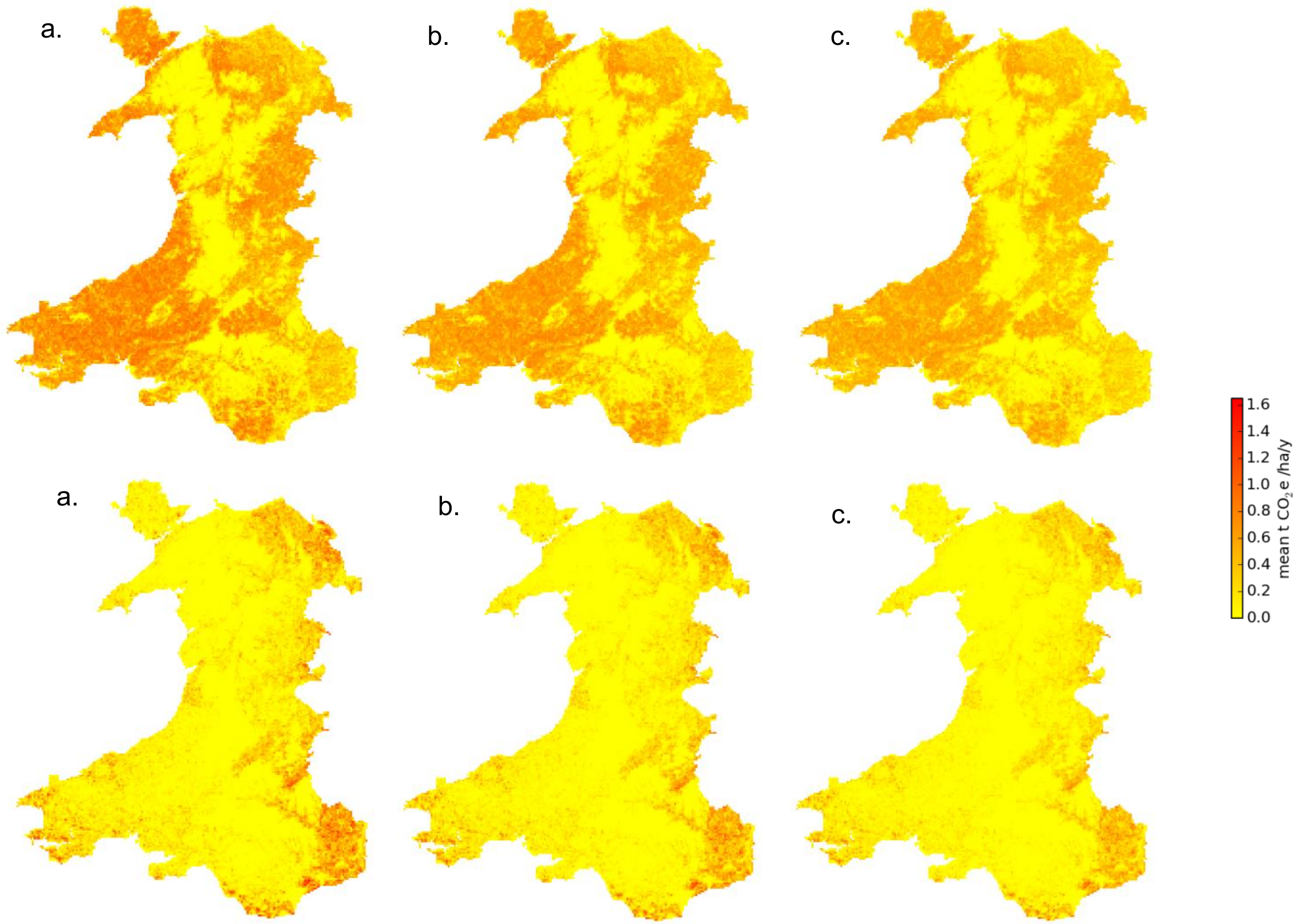

Figure 3: ECOSSE simulated N_2O fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable lands (below) at baseline (a) and 20% (b) and 40% (c) reduced N fertilizer application rates.

Figure 4: ECOSSE simulated annual GHG fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable (below) lands at baseline (a) and 20% (b) and 40% (c) reduced N fertilizer application rates.

3.3 Effects of climate change on GHG and SOC fluxes for Wales

The ECOSSE model was applied to assess the effects of climate change on GHG and SOC fluxes and NPP for Wales. Two future climate scenarios (low and high; 2015-2050) were compared with the baseline climate (1961-1990) as described in Section 2.3.2. Figures 5 and 6 show the ECOSSE predicted annual net GHG and SOC fluxes, from the different ecosystems, at baseline climate compared to the low and high climate scenarios. Under climate change, the net GHG fluxes, for all ecosystems and both climate scenarios, were slightly decreased compared to the baseline climate (Figures 5 and 6). The NPP under the low and high warming climate is 8% and 10% higher compared with that at baseline, respectively. Future N_2O flux values would slightly increase compared to those under the baseline climate scenarios (Table 3; Appendices 6 and 7). The N_2O flux difference between the low and high climate scenarios was very small (Table 3). However, all ecosystems remain a small sink for CH_4 (Appendices 8 and 9). For all ecosystems, SOC fluxes were increased by climate change as shown in Table 3 and Appendices 10 and 11. Under climate change, all ecosystems become small sources for SOC in place of a sink under the baseline climate scenario. Generally, under climate change Welsh soils will continue to have a positive net GWP. The overall annual net GHG balances were slightly lower (C uptake of 0.181 and 0.195 t CO_2e /ha/y) for the low and high climate scenario, respectively, compared to the baseline climate (0.200 t CO_2e /ha/y) (Table 3). The difference between the two climate scenarios is, however, small (about ±2%).

Table 3: ECOSSE simulated mean annual GHG, SOC fluxes and net GHG balance (t CO_2e / ha/y*) at baseline climate and the low and high climate scenarios to 2050, for Wales.

Gas flux	Baseline	Low climate scenario	High climate scenario
N_2O	0.200	0.208	0.212
CH_4	-0.014	-0.004	-0.005
SOC	-0.013	0.023	0.013
Net GHG balance	0.199	0.181	0.195

***** Where GWP for N_2O is 296 and for CH_4 is 23 times greater than CO_2 over a 100 year period.

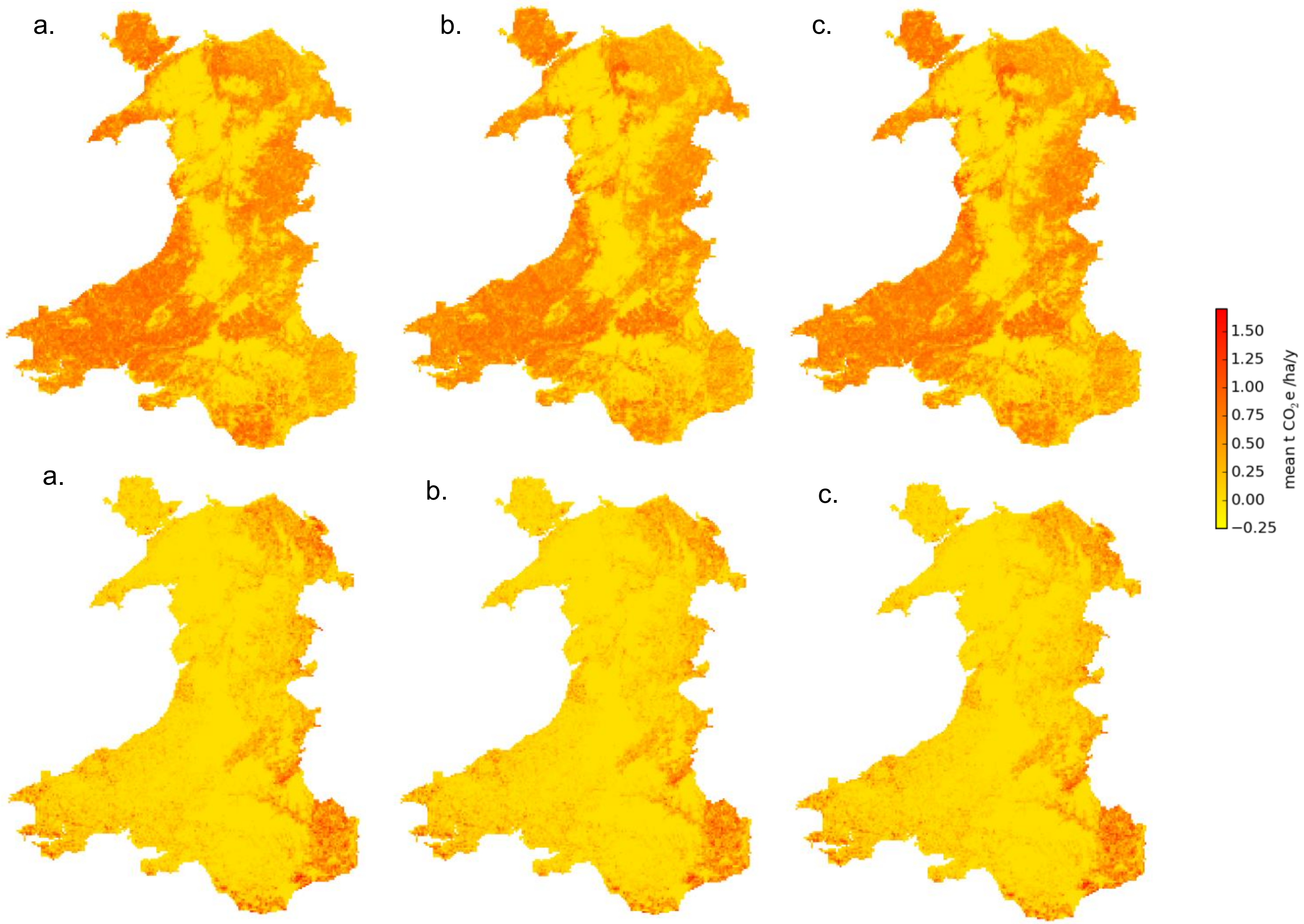

Figure 5: ECOSSE simulated GHG fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable (below) lands at baseline (a), low (b) and high (c) climate scenarios.

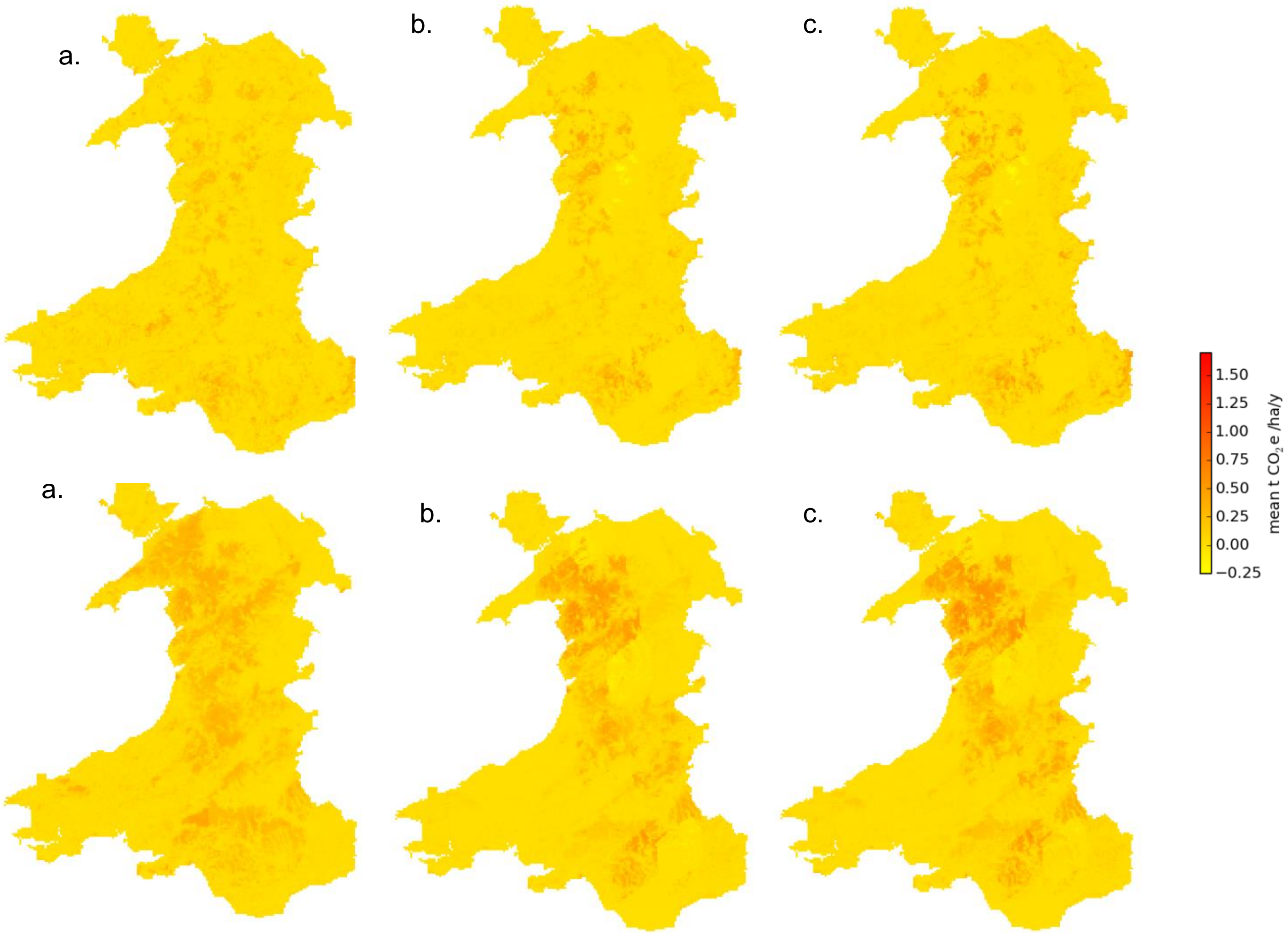

Figure 6: ECOSSE simulated GHG fluxes (t CO_2e /ha/y) from the Welsh forest (above) and natural (below) ecosystems at baseline (a), low (b) and high (c) climate scenarios.

4. Discussion

4.1 Evaluation of the ECOSSE model and GHG and SOC fluxes at baseline

In this study, the ECOSSE model was used to predict GHG and SOC fluxes for Wales. The overall annual net GHG balance of 0.199 t CO_2e /ha/y predicted by ECOSSE for the baseline (1961-1990), shows that Wales has a positive net GWP equivalent to a net annual loss of 54 kg C /ha/y. The calculated total net annual fluxes from the whole of Wales are estimated at 0.37 Mt CO_2e /y, driven primarily by N_2O fluxes. The model responded appropriately to changes in air temperature, timing of precipitation events, land use and system management, which have strong impacts on GHG and SOC fluxes. ECOSSE estimated credible N_2O fluxes and showed sensitivity to N fertilizer application rate. The N fertilizer application rate estimated by ECOSSE, calculated from the crop N demand, is equivalent to 137 kg N /ha/y. Compared with the measured average field N fertilizer application rate, for Wales in the period 1974-2012, of 121 kg N /ha/y (BSFP, 2012), the ECOSSE estimation is a little higher, but reasonable. This is especially promising considering that the field N fertilizer application rate in Wales has fallen in recent years, hence the average for the modelled period is likely to be higher than the quoted value (BSFP, 2013).

ECOSSE was previously tested and showed good agreement between measured and modelled N_2O results (Bell et al., 2012; Khalil et al., 2013). Higher N_2O fluxes were observed from the grass and arable ecosystems compared to the forest and natural ecosystems due to the addition of N fertilizer. The fluxes were also higher in coastal areas (Appendix 1) where rainfall was higher and, consequently, soil moisture was high. Both soil moisture and soil N availability are co-required for high N_2O fluxes. Similar results at field level studies have been demonstrated in maize (McSwiney and Robertson, 2005) and in forest and grassland systems (Maljanen et al., 2002; Abdalla et al., 2009a). Soil moisture stimulates denitrification by temporarily lowering oxygen diffusion into the soil (Dobbie and Smith, 2001) as well as by increasing the solubility of organic carbon and nitrate (Bowden and Bormann, 1986). The strong relationship between N_2O fluxes, and the interaction between soil moisture and soil nitrate, suggest that a high rainfall in winter and early spring, together with soil properties such as drainage characteristics, are important in the regulation of N_2O flux. Fluxes of N_2O were also increased with increasing air temperature (Appendix 1). Most soil processes e.g. like decomposition, N mineralisation; nitrification and nutrients uptake are dependent on temperature (Stark and Firestone, 1996; BassiriRad, 2000; Shaver et al., 2000; Shaw and Harte, 2001), and consequently GHG emissions (Raich and Schlesinger, 1992; Abdalla et al., 2009b).

ECOSSE predicted very low soil CH_4 fluxes across Wales. However, although fluxes under mineral soils are generally low (Abdalla et al., 2014a), fluxes from areas with organic soils, which are typically poorly-drained in their natural state (Levy et al., 2012), are underestimated by the model. Khalil et al. (2013) also reported that ECOSSE predicted CH_4 fluxes from Irish croplands less accurately. The model uses water table depth to simulate CH_4 production from soils (Bradbury et al., 1993, Smith et al., 1996). However, due to unavailability of observed spatial water table input data for the model, all soils in the simulations were assumed to be freely drained, with no specific water table depth. This assumption resulted in some uncertainty in the simulated CH_4 fluxes in areas of saturated soils (Worrall et al., 2011). Additionally, the model simulates the oxidation of atmospheric CH_4, which, under aerobic conditions, can lead to the soil being a net consumer of CH_4. For all investigated ecosystems, SOC fluxes at baseline were negative representing small sink of atmospheric C. This is because, prior to each simulation, the model was initialised based on the assumption that the SOC in the soil column is at stable equilibrium under the initial land use at the start of the simulation.

The effect of soil types on GHG and SOC fluxes in this spatial study is complicated but can be understood by looking to the key soil properties used by ECOSSE to modulate gas fluxes from soil. Soil clay content has large effect on soil organic matter decomposition. As clay content increases, a smaller proportion of decomposed C would be lost as CO_2 (i.e. the efficiency of decomposition increases), and a greater proportion is retained in the biomass and humus soil organic matter pools. Clay forms aggregates that physically protect SOC from microbial decomposition (Rice, 2002). Thus the relative SOC losses would be small for areas in which soil has high clay content. Soil pH also has a significant effect on the rate of soil organic matter decomposition (Andersson and Nilsson, 2001; Abdalla et al., 2014b). In ECOSSE, the pH rate modifier for aerobic decomposition decreases linearly as pH drops below 4.5. Ye et al. (2012) reported that low pH limited microbial metabolism. Bulk density affects the rate of CH_4 oxidation (i.e. consumption of CH_4). Some empirical evidence showed that soils with a low bulk density have higher rates of methane oxidation (Borken and Brumme, 1997). Here soils are more permeable which allow atmospheric methane and oxygen to diffuse freely into the soil (Dörr et al., 1993). However, because in this study ECOSSE simulated CH_4 production rates were generally very low, bulk density has no significant effect on the net GHG balance. Emission factor was not calculated as the model was not run to simulate crops without application of N fertiliser.

4.2 Effects of the Glastir measure of reducing nitrogen on GHG and SOC fluxes for Wales

In this simulation, ECOSSE was applied to assess the efficiency of the Glastir measure of reducing N fertilizer application rate to reduce GHG and SOC fluxes. Fertilizer was applied in the form of inorganic N fertilizer at a rate equal to the annual crop N demands as mentioned earlier (Section 2.4.4). There are no databases that define application of N fertilizer spatially. ECOSSE therefore estimates the N fertilizer application rate depending on the crop N demand. This is the only way to apply N fertilizer in ECOSSE without having spatially disaggregated application rates. The model is not sensitive to grazing or addition of animal manure. However, back-calculating the N amount applied at baseline using our N_2O figures and comparing to the average N fertilizer application rate for Wales (1974-2012) gave a reasonable value of 137 kg N /ha/y. Heavy utilization of synthetic N fertilizers in the grass/ arable lands typically results in high N_2O fluxes from soils. However, reducing N fertilizer application rate by 20 and 40% from the baseline resulted in 12% and 22% less N_2O fluxes and thereby, lower net GHG emissions. Nitrous oxide production has a non-linear response to mineral N content of the soils, with the curve flattening off at high mineral N (McSwiney and Robertson, 2005) as at lower levels, the N is taken up by the crop, as only surplus N is available for denitrification to N_2O.. Nitrous oxide has a high GWP, thus reducing its emissions would result in beneficial change to net GHG balance (IPCC, 2007). Availability of mineral N has a direct influence on N_2O production by provision of N for both nitrification and denitrification (Baggs and Blum, 2004; Abdalla et al., 2010). Reduced N fertiliser inputs lead to slow denitrification rate and a lower proportion of denitrified N emitted as N_2O. Nitrous oxide fluxes from soils occur in short-lived bursts following the application of N fertilizers (Leahy et al., 2004). The spatial variability in N_2O fluxes is high (Van den Heuvel et al., 2008) and controlled by interacting abiotic and biotic factors, such as plants, micro-organisms, precipitation and nutrients. These factors may vary on an annual basis with a significant effect on the magnitude of the N_2O flux. The flux is also expected to vary on a temporal basis depending on the dominant controlling factor (Mummey et al., 1997). However, less reduction in N_2O fluxes was observed in coastal areas where precipitation is high, whilst higher reduction was observed in drier areas of the country. Higher soil water content leads to a higher denitrification rate. However, although the proportion of denitrified N emitted as N_2O decreases, the net result is an increase in N_2O emissions as soil water content increases. This ECOSSE response reflects the empirical evidence for N_2O emissions increasing as soil water content increases (e.g. Schindlbacher et al., 2004; Luo et al., 2013). Abdalla et al (2010) reported that reducing fertilizer application rate by 50% for low input agriculture in Ireland is an acceptable strategy in that there was no significant effect on grain yield or quality in terms of required protein content, but it significantly reduced seasonal fluxes of N_2O.

ECOSSE does simulate the effects of N availability on C cycling. It works as follows: The N:C ratio of the biomass (BIO) and humus (Hum) pools have fixed N:C ratio that must be maintained. As C and N flow into these pools following decomposition of the decomposable plant material (DPM) and resistant plant material (PRM) any extra N required to maintain the BIO and HUM N:C is taken from the mineral N pools (NH_4 and NO_3). If insufficient N is available in these pools to meet the demand then the N:C of the organic matter entering the BIO and HUM is increased by decreasing the efficiency of decomposition (i.e. more CO_2 is given off, and less C is retained in the organic matter) . More explanation is given in the ECOSSE manual (Smith et al., 2010).

4.3 Effects of climate change on GHG and SOC fluxes for Wales

The effects of climate change on GHG and SOC fluxes for Wales until 2050 were investigated using two climate scenarios, low and high. Although temperature under climate change scenarios was higher than under the baseline climate scenario, fluxes of N_2O were not increased due to climate change. Under climate change, soil nitrogen increases due to increasing mineralization with changing temperature and precipitation (Wennman and Katterer, 2006; Abdalla et al., 2009a). Soil mineral nitrogen and N mineralization are the main sources of N_2O production (Bouwman, 1990; Abdalla et al., 2010). Soil characteristics and environmental conditions affect this mineralization (Schoenau and Campbell, 1996). Changes in precipitation (Izaurralde et al., 2003; Mearns, 2003), temperature (Fiscus et al., 1997) and atmospheric carbon dioxide concentrations could also have positive effects on the productivity of plants (Anwar et al., 2007). Many factors are responsible for CO_2 effects (i) high CO_2 directly affects C availability by stimulating photosynthesis and reducing photorespiration (Akita and Moss, 1973) (ii) high CO_2 concentrations reduce stomatal conductance (Morison and Gifford, 1984) which decreases the transpiration rate per unit leaf area. Low transpiration rates increase the leaf temperature and thereby further increase photosynthesis (Acock, 1990). An increase in photosynthesis combined with a decrease in transpiration result in an increase in the water use efficiency (iii) increases in CO_2 decrease the crop N concentration (Hocking and Meyer, 1991). In this study, the NPP under climate change was estimated to be 8-10% higher compared to baseline. An increase in grass dry matter production in Ireland due to climate change for the period 2061-2090 was also predicted by Fitzgerald et al (2009) and Abdalla et al. (2010). The fluxes of N_2O have a threshold response to N, and the amount of N lost to the atmosphere depends on the amount of N taken by plants (McSwiney and Robertson, 2005; Abdalla et al., 2010). The SOC fluxes were increased under both future climate scenarios compared to the baseline climate with a small difference between the two scenarios. Future high CO_2 concentration can increase plant photosynthesis, growth, belowground C input and substrate leading to greater root and microbial activities and respiration (Edwards and Norby, 1999; Zak et al., 2000; Anderson et al., 2001). Previous studies indicate that prediction of soil C fluxes in response to climate change should consider changes in biotic factors i.e. plant growth and substrate supply and abiotic factors i.e. temperature and moisture (Wang et al., 2007; Xia et al., 2009). Temperature is one of the main driving factors affecting C flux from soils (Tang et al., 2006; Jabro et al., 2008). The increase in plant growth and aboveground biomass produces more litter-fall and contributing to higher C loss through soil respiration (Zak et al., 2000; Deng et al., 2010). Both soil organic matter decomposition and microbial response to other perturbations, such as fertilisation, temperature and rainfall, can increase (Wennman and Katterer, 2006). However, contradicting findings about the effects of rainfall and soil moisture are reported in the literature with increased (Jabro et al., 2008) or unaffected (Ding et al., 2007) C fluxes.

In this study, CH_4 fluxes were low and not affected by climate change. Future overall net GHG balance from Welsh soil is slightly decreased compared to the baseline climate but remain a C equivalent source. However, the magnitude of the source could be underestimated due to ECOSSE potentially underestimating CH_4 fluxes. Both changes in SOC fluxes and plant C inputs (i.e. plant growth) are due to changes in climate, mainly arising through temperature and soil moisture (Smith et al., 2007). This suggests that if the current N fertilizer application rate continues, climate change up to the year 2050 would not significantly affect net GHG balance or NPP from Welsh soils.

5. Conclusions

1. ECOSSE provides broadly reliable predictions of GHG and SOC fluxes for Wales.
2. ECOSSE estimated mean annual net GHG balance at baseline climate of 0.2 t CO_2e /ha/y, which is equivalent to a net C loss of 54 kg C /ha/y.
3. The Glastir measure of reducing N fertilizer to reduce GHG and SOC fluxes is efficient and could reduce the annual net GHG balance from 0.20 to 0.17 (for 20% N reduction) and 0.15 (for 40% N reduction) t CO_2e /ha/y, respectively.

4. Climate change will not significantly affect net GHG fluxes or NPP from Welsh soils. The difference between the two climate scenarios is, however, small (about ±2%).

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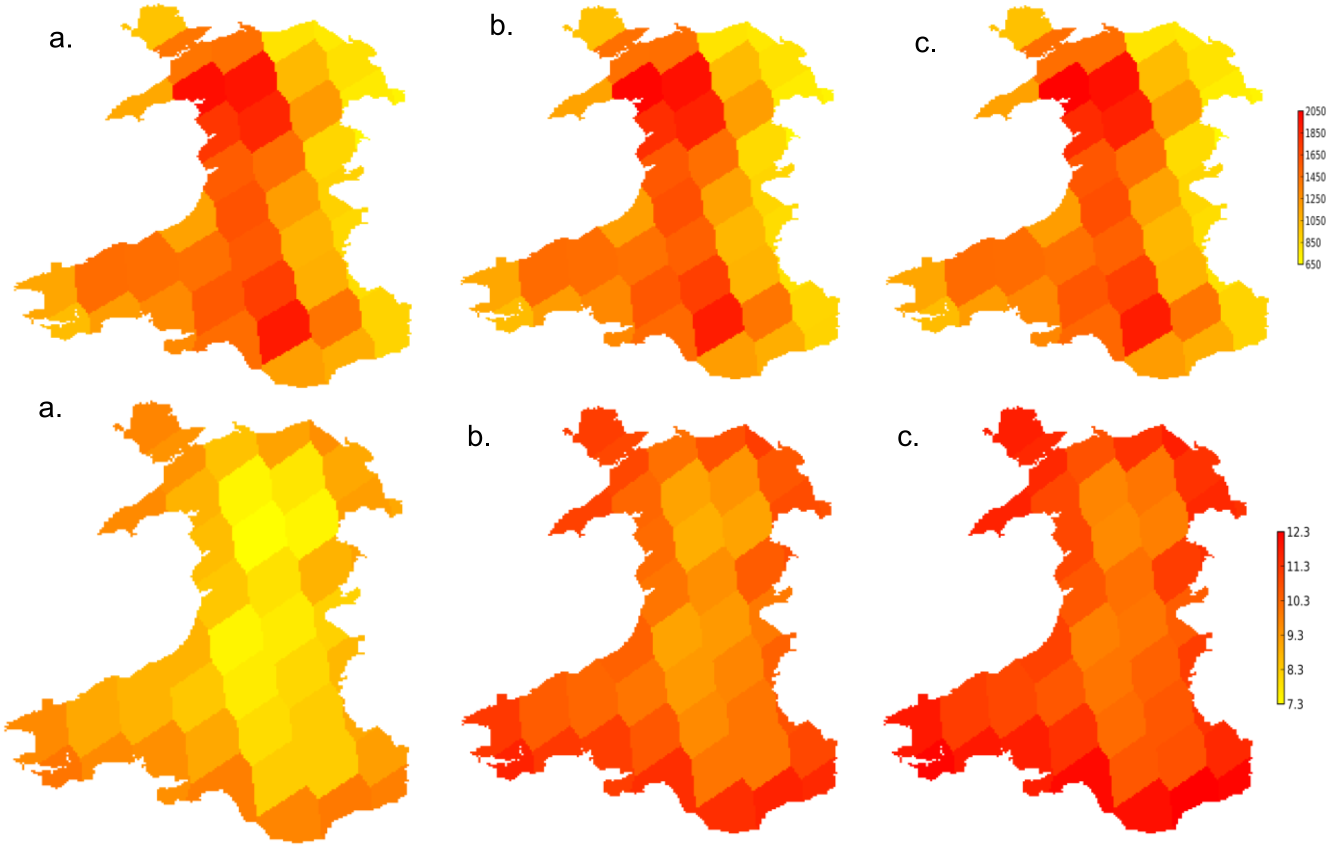
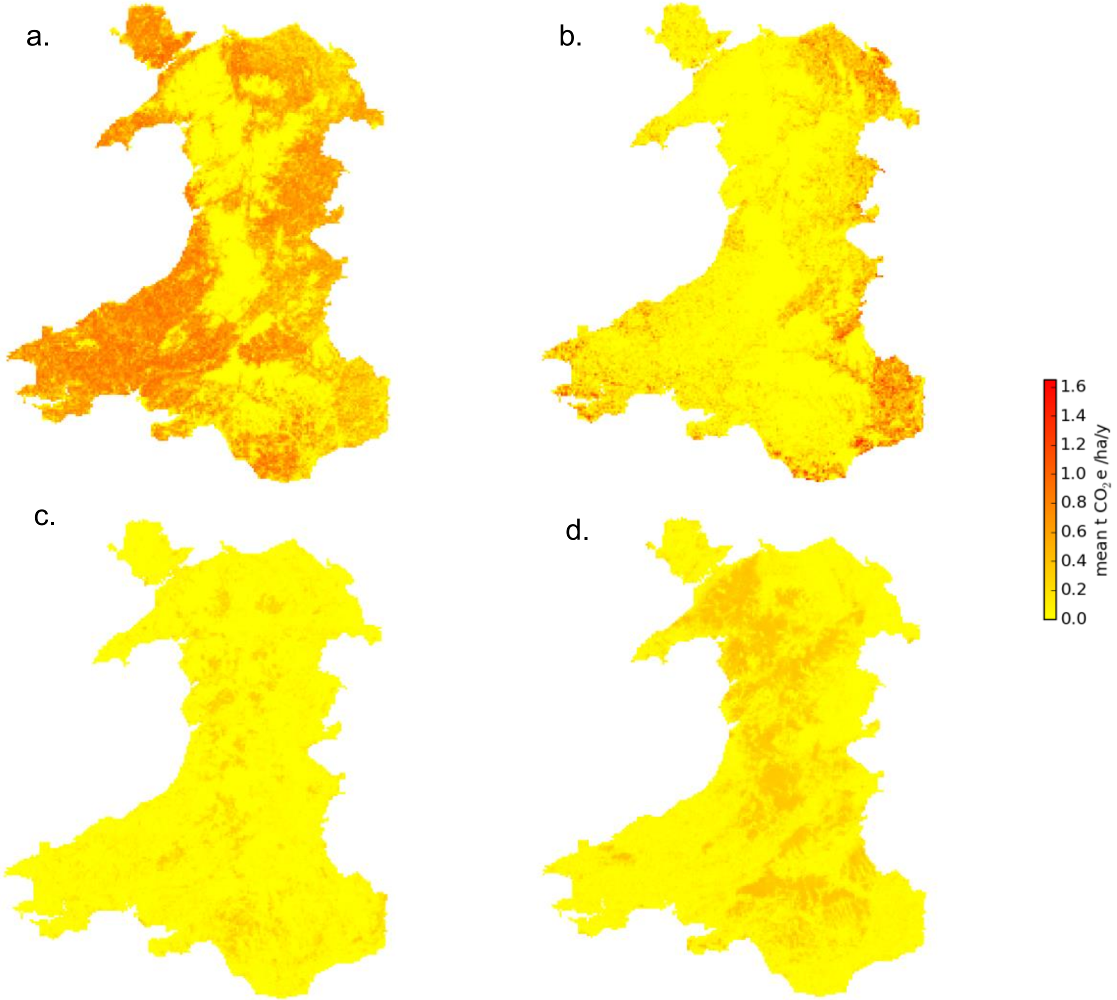
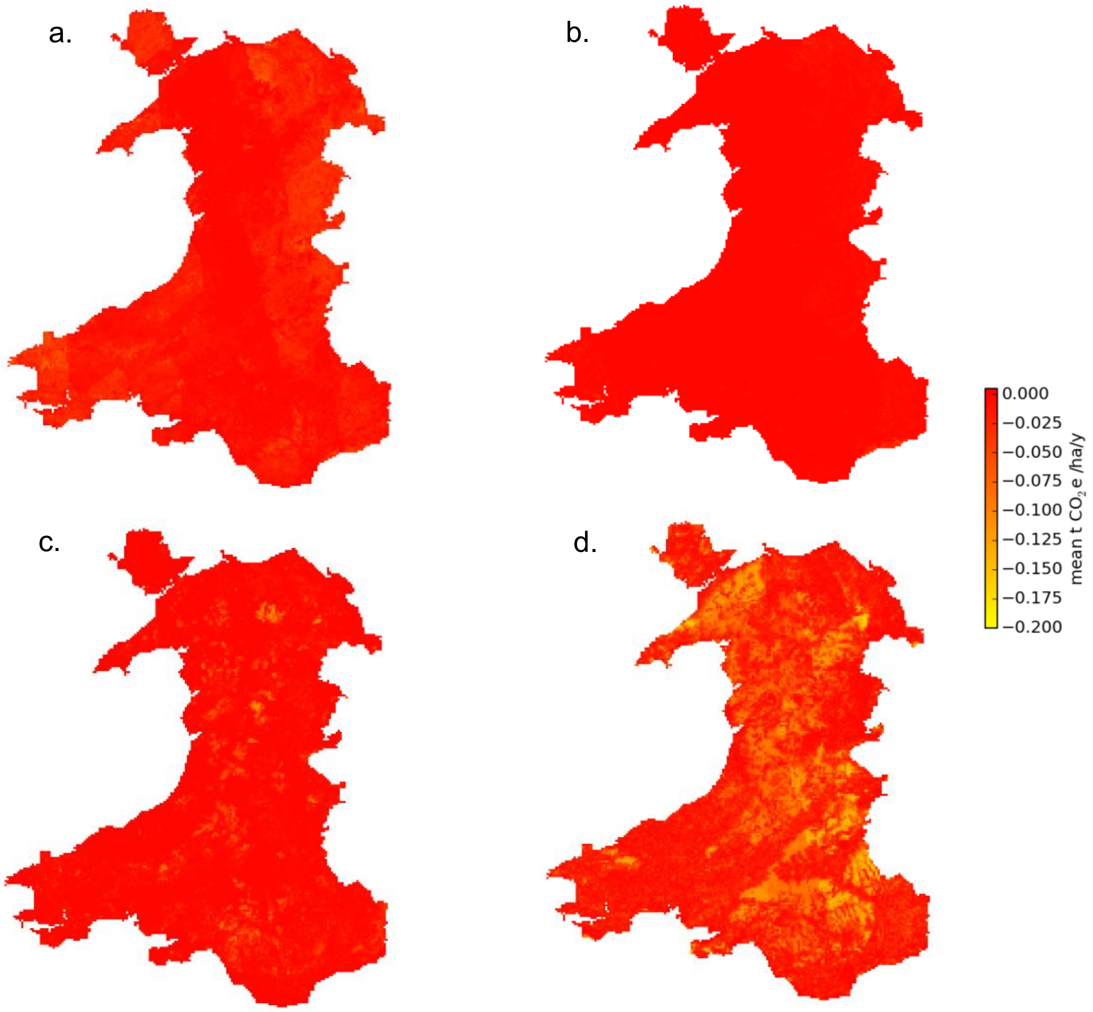
Appendices



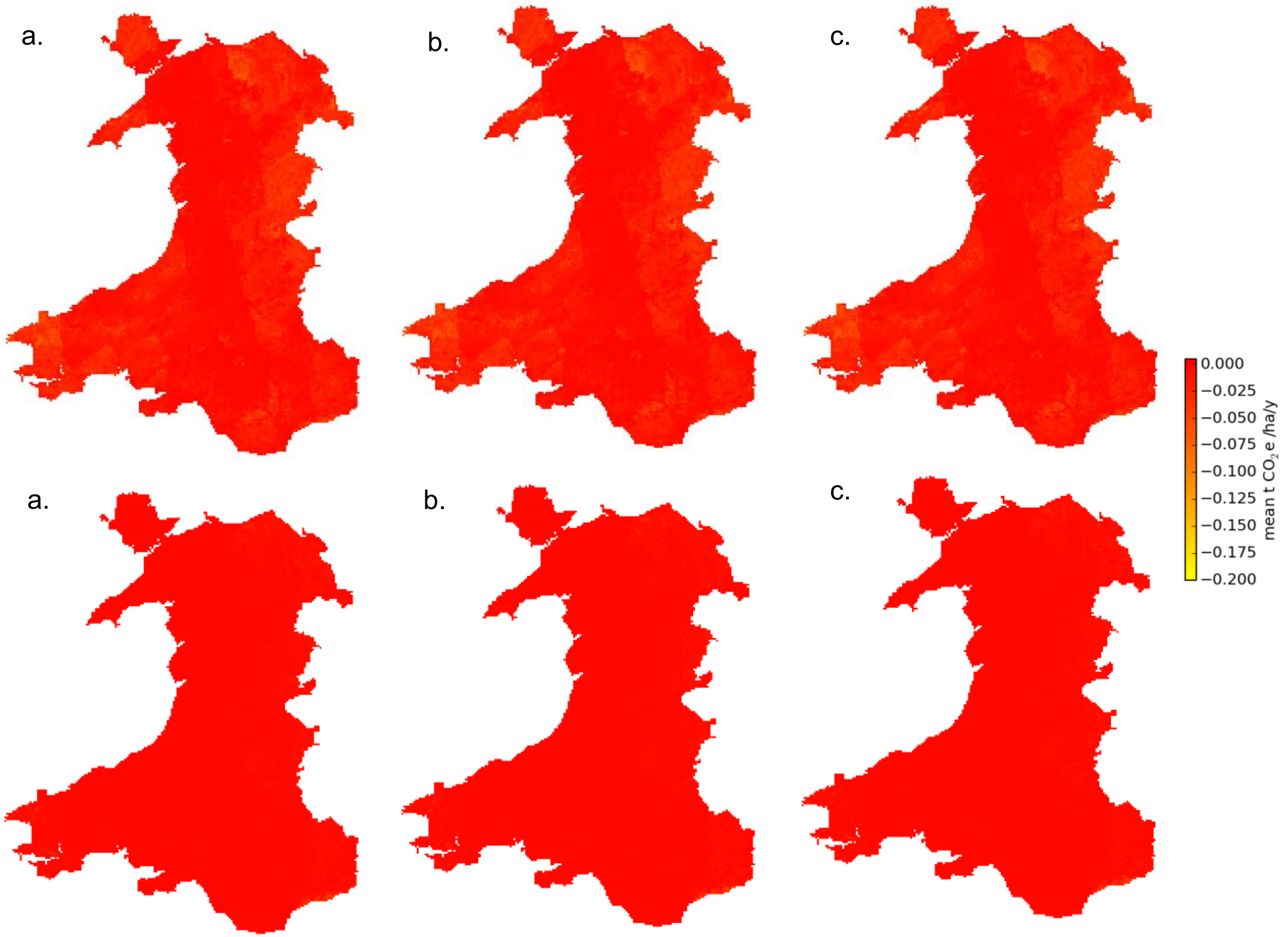
Appendix 1: Mean precipitation (above; mm) and air temperature (below; ^{o}C) at baseline (a), low (b) and high (c) climate scenarios.



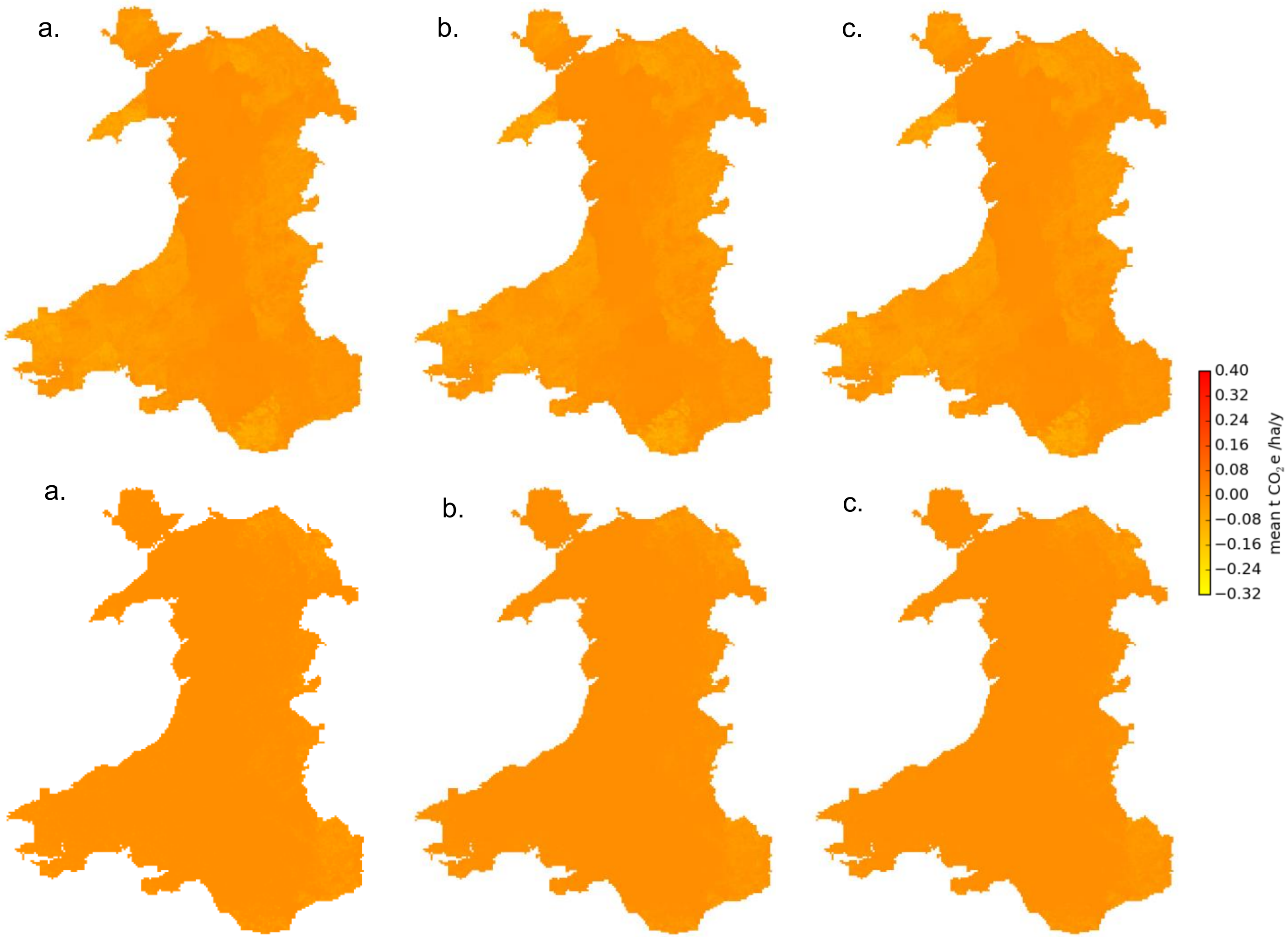
Appendix 2: ECOSSE estimated mean annual N_2O fluxes (t CO_2e /ha/y) from the Welsh grassland (a), arable land (b), forest (c) and natural ecosystem (d), at baseline climate (1961-1990).



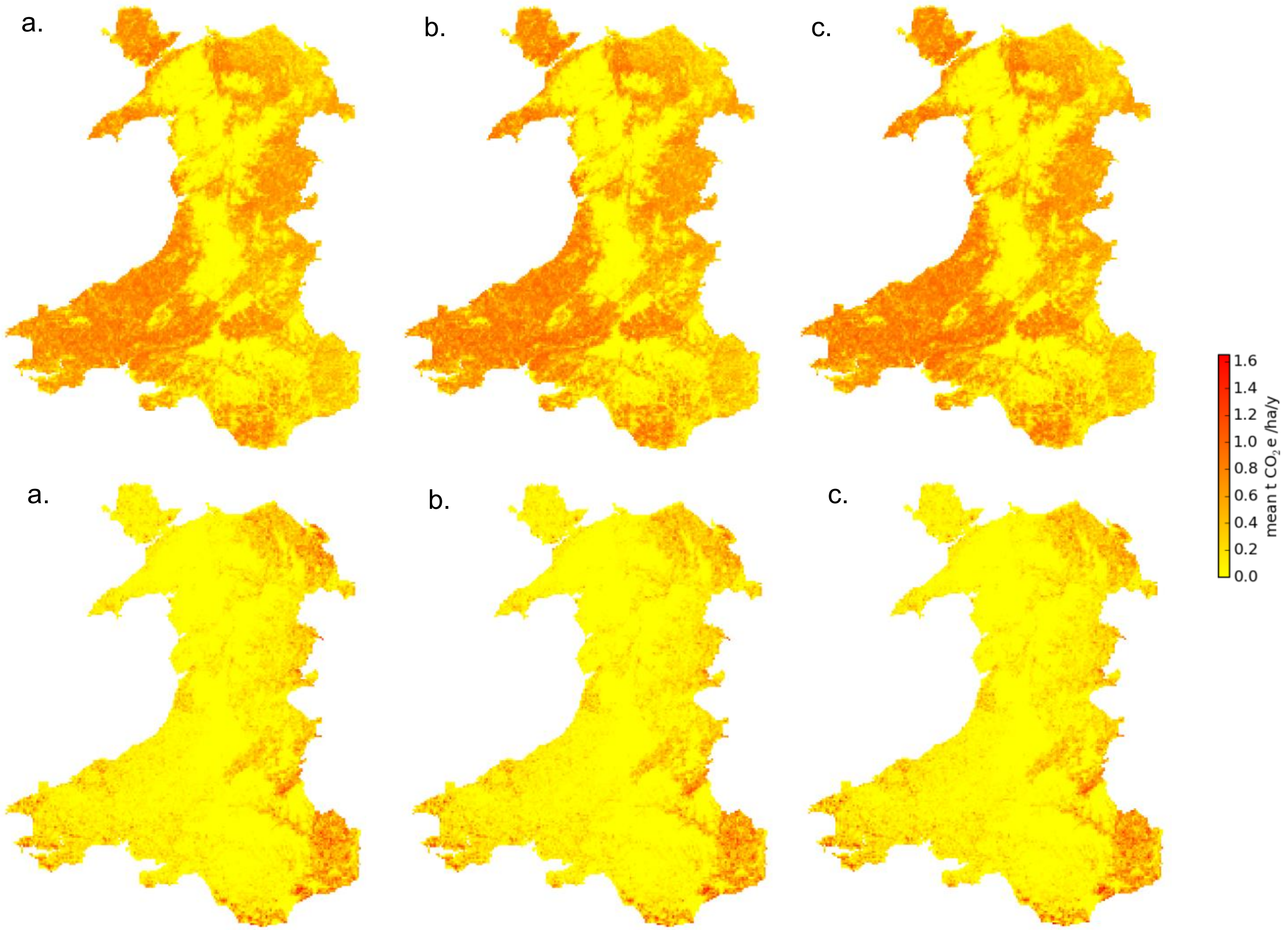
Appendix 3: ECOSSE estimated mean annual CH_4 fluxes (t CO_2e /ha/y) from the Welsh grassland (a), arable land (b), forest (c) and natural ecosystem (d), at baseline climate (1961-1990).



Appendix 4: ECOSSE simulated CH_4 fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable lands (below) at baseline (a) and 20% (b) and 40% (c) reduced N fertilizer application rates.

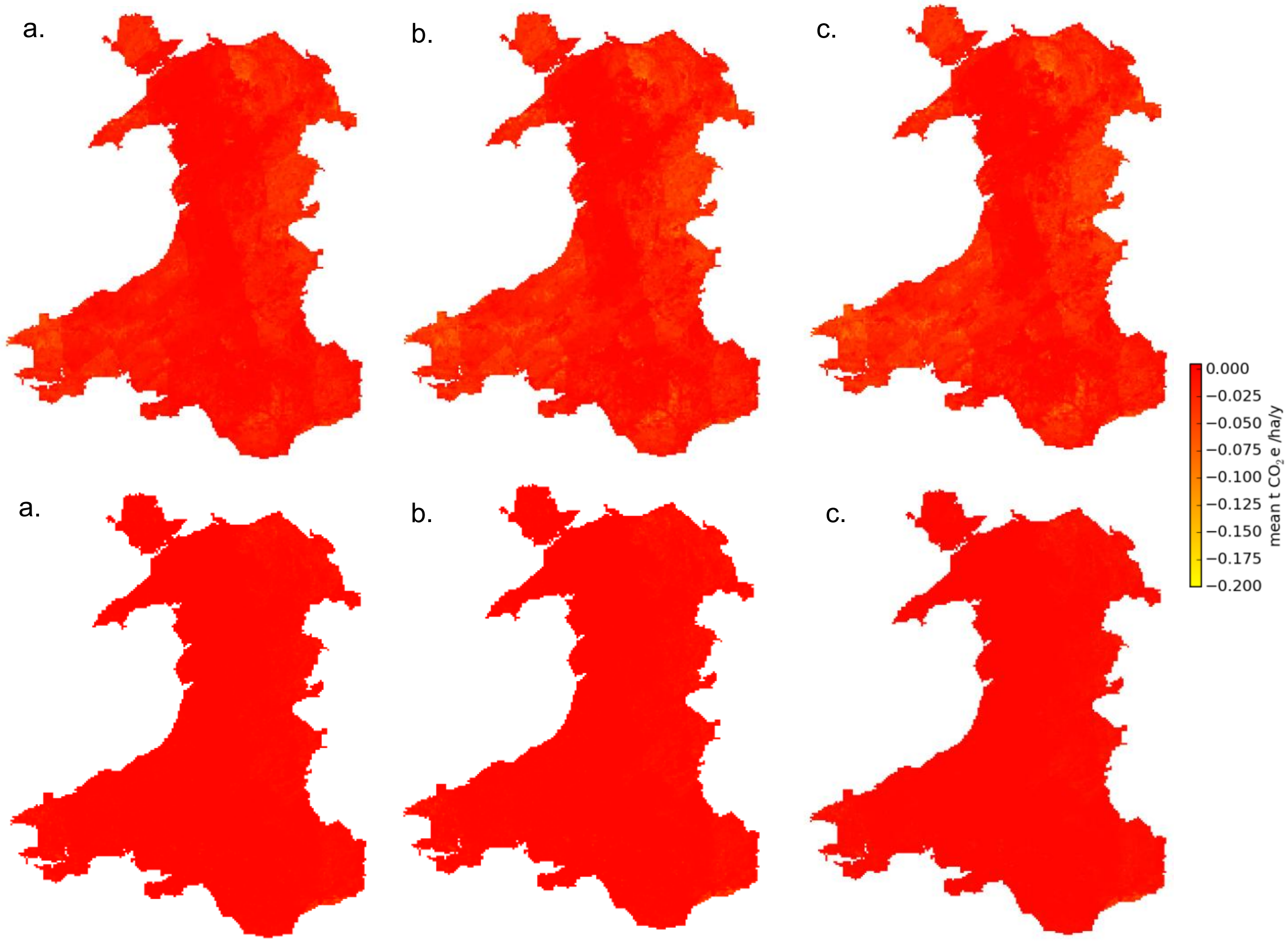


Appendix 5: ECOSSE simulated SOC fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable lands (below) at baseline (a) and 20% (b) and 40% (c) reduced N fertilizer application rates.

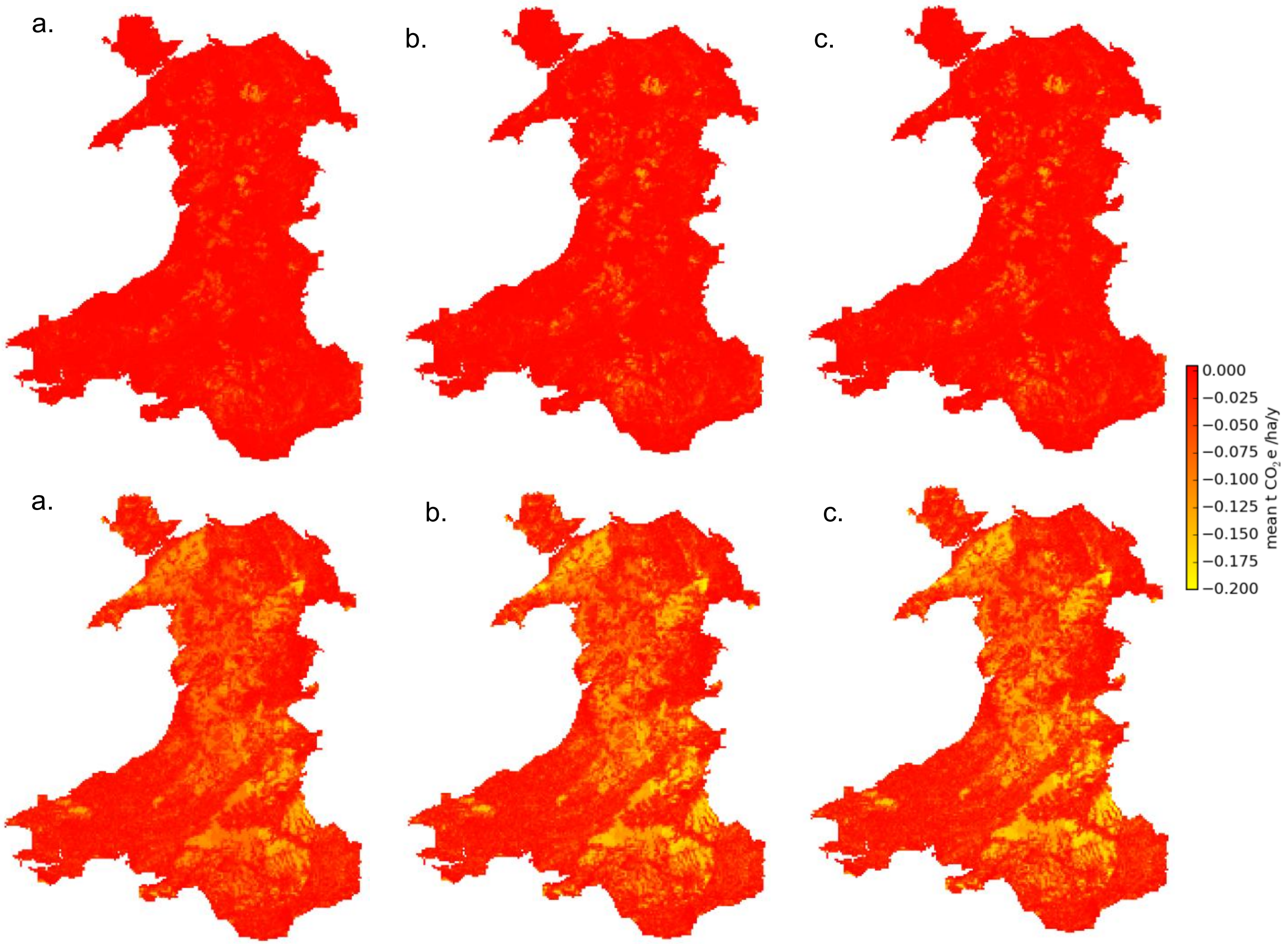


Appendix 6: ECOSSE simulated N_2O fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable (below) lands at baseline (a), low (b) and high (c) climate scenarios.

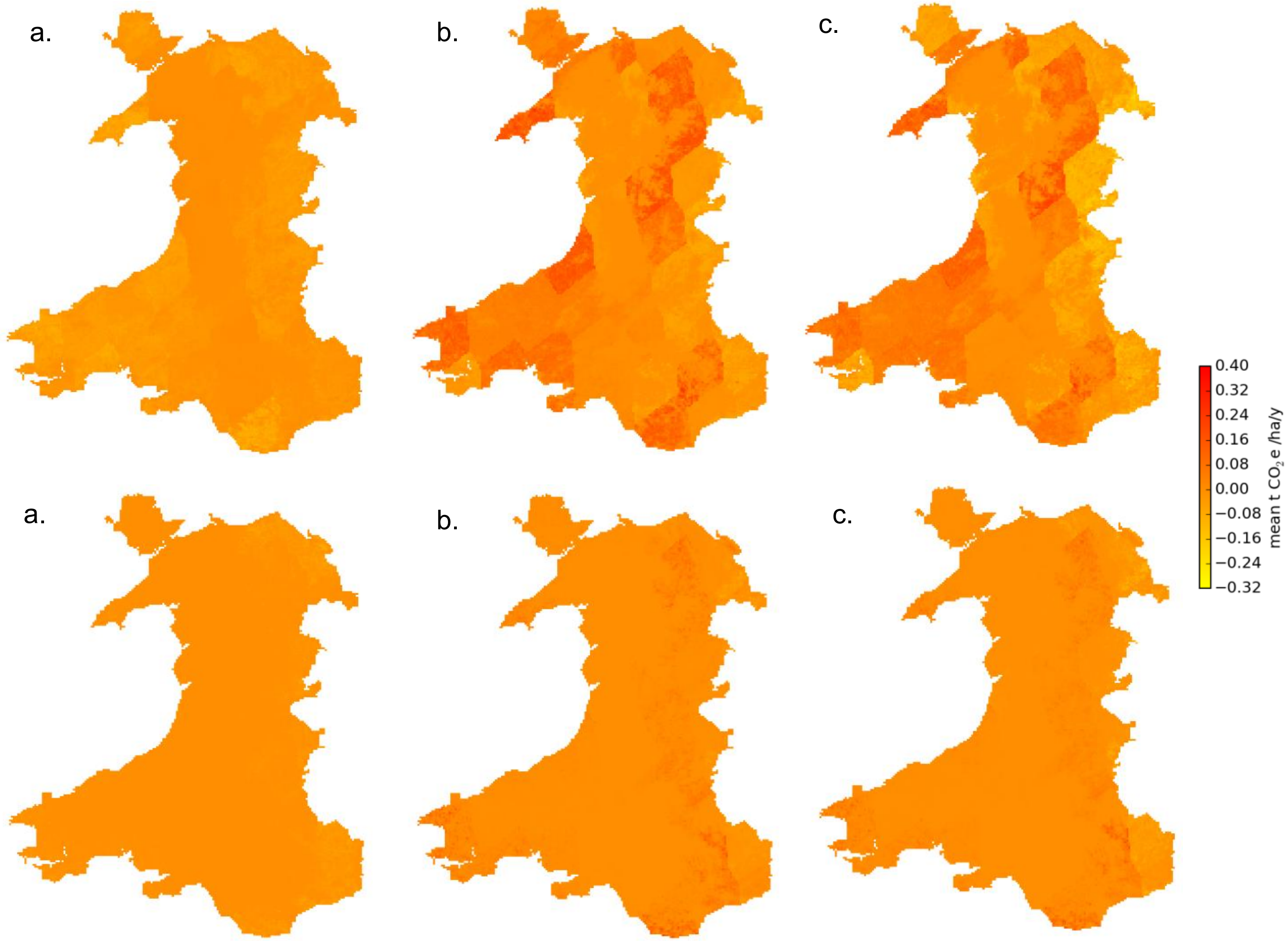
Appendix 7: ECOSSE simulated N_2O fluxes (t CO_2e /ha/y) from the Welsh forest (above) and natural (below) ecosystems at baseline (a), low (b) and high (c) climate scenarios.



Appendix 8: ECOSSE simulated CH_4 fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable (below) lands at baseline (a), low (b) and high (c) climate scenarios.



Appendix 9: ECOSSE simulated CH_4 fluxes (t CO_2e /ha/y) from the Welsh forest (above) and natural (below) ecosystems at baseline (a), low (b) and high (c) climate scenarios.



Appendix 10: ECOSSE simulated SOC fluxes (t CO_2e /ha/y) from the Welsh grass (above) and arable (below) lands at baseline (a), low (b) and high (c) climate scenarios.

Appendix 11: ECOSSE simulated SOC fluxes (t CO_2e /ha/y) from the Wlsh forest (above) and natural (below) ecosystems at baseline (a), low (b) and high (c) climate scenarios.ppendix 11: Mean precipitation (above; mm) and air temperature (below; ^{o}C) at baseline (a), low (b) and high (c) climate scenarios.

Appendix 6.3

WP9. Climate Change Mitigation and Diffuse Water Pollution Mitigation

A Review of Model Assumptions

Dave Chadwick, Steve Anthony, Rachel Taylor, Janet Moxley, Mohamed Abdalla and Pete Smith

Introduction

Welsh Government has developed a targeted approach to the delivery of improved environmental goods from farmland via the new Glastir Programme. Farmers accrue points for adopting a range of on-farm measures aimed at protecting soil C, reducing greenhouse gas (GHG) emissions, improving water quality and enhancing biodiversity.

The Glastir Monitoring and Evaluation Programme (funded by WG and led by CEH) aims to assess the success of the Glastir Programme in delivering it's goals. As such, WP9 will quantify the potential of Glastir measures to increase carbon storage (above and below ground) and reduce emissions of nitrous oxide (N_2O) and methane (CH_4). This will be achieved by taking an ensemble modelling approach, since no one model is able to account for all the sources of GHG emissions and carbon stores.

The four models used in this study are: i) the ADAS modelling framework (Anthony et al., 2012), ii) the Landuse, Landuse Change and Forestry (LULUCF) emissions reporting system (IPCC, 2003; IPCC, 2006), iii) the Bangor Carbon Footprinting model (Taylor et al., 2010), and iv) the mechanistic model ECOSSE (Smith et al., 2007; Smith et al. 2010a, b). Table 1 summarises the sources of N_2O and CH_4 emissions and C stores each model can account for.

IPCC Approach	Methane	Nitrous oxide	Carbon Dioxide	Carbon stocks	Diffuse water pollutants
Tier 1 (some Tier 2)	**Bangor Carbon Footprinting Tool**				
	Ruminant and manure	Direct and indirect + embedded losses	CO_2 energy, incl. embedded losses	Soil and vegetation	
Tier 1 (some Tier 2)	**ADAS Tool**				
	Ruminant and manure	Direct and indirect	CO_2 energy		NO_3,NH_4, P,sediment
Tier 1	**LULUCF**				
	Soil Fires (wildfires and forest clearance)	Direct from soil disturbance and fires	Soil respiration (Rh)	Soil and vegetation	
Tier2/Tier 3	**ECOSSE**				
	Soil	Direct and indirect	Soil respiration	Soil and vegetation	

Table 1. Sources of GHG emissions and soil Carbon stocks predicted by the different modelling tools.

All of the models incorporate specific assumptions and use values of emission factors or rates of carbon accumulation based on basic principles, empirically derived data, and expert judgement representing the best knowledge at the time of construction. They have been updated and revised as new and better knowledge has become available. This review summarises key assumptions and values used for emission factors and rates of carbon accumulation for each of the four models, comparing these assumptions and values with recent literature (grey and published), which could be used to update the models where appropriate. This information may help to explain any differences in model outputs for a given change in farming practices.

ADAS Modelling Framework (Steve Anthony)

Model description

In the ADAS model, mitigation impact is quantified using the Wales Diffuse Pollutant Emissions Modelling Framework developed under the previous project, 'Eco Systems Lot 3' (Anthony et al., 2012). In this framework present-day pollutant emissions are first calculated by application of a range of empirical and process based models including PSYCHIC (Davison et al., 2008) for phosphorus and sediment, and N-CYCLE, NITCAT and MANNER (Scholefield et al., 1991; Lord, 1992; Chambers et al., 1999) for nitrate, and IPCC tier one and two for N_2O and methane (Baggott et al., 2006). Each model is modified to provide an explicit source apportionment of emissions by source, area and pathway for representative farm system types across Wales. The impact of a mitigation method is then calculated as a percentage reduction against emissions from targeted coordinates. The reductions may be trivially calculated if the mitigation option maps directly to a modelled pollutant source (e.g. a reduction in fertiliser nitrogen), or are based on a synthesis of experimental literature and further computer modelling for representative scenarios. The impact of a mitigation method depends on the relative contribution of the targeted coordinates to total pollutant emissions, and the extent to which a mitigation method is already widely practiced.

Model outputs

ADAS Model outputs include: gases - enteric methane, manure methane, direct soil N_2O, N_2O associated with nitrate leaching (indirect N_2O), CO_2 from energy use; diffuse water pollution – nitrogen, phosphorus, sediment

Recent applications of the model

The ADAS Modelling framework was used in a previous Welsh Government funded project to assess the contribution of previous Welsh agri-environment schemes to the maintenance and improvement of soil and water quality, and to the mitigation of climate change (Anthony et al., 2012).

Emission Factors

The ADAS modelling system generally uses IPCC Guideline (1996/2000) emission factors for calculating CH_4 and N_2O emissions from agriculture, with the exception of FracLeach which is calculated from the ADAS MANNER, NITCAT and NEAP-N nitrate leaching models. Default emission factors are used with country specific management and productivity data (e.g. fertiliser use and dairy cattle milk yield) and Adherence to IPCC Guidelines means that model is consistent with UK Inventory methodology. Emission factors do not necessarily reflect the Welsh climate and soil attributes for N_2O, e.g. effect of pH, organic matter content and aeration.

However, the UK GHG Inventory is to move to the IPCC 2006 Guidelines, which will change the following key emission factors:

- Methane conversion factor for cattle from 6.5 to 6%
- Methane conversion factor for slurry storage from 39 to 10%
- Methane conversion factor for FYM storage from 1 to 2%
- Nitrous oxide emission factor for slurry storage from 0.1 to 0%
- Nitrous oxide emission factor for FYM storage from 2 to 0.5%
- Nitrous oxide emission factor for poultry manure storage from 2 to 0.1%
- Nitrous oxide emission factor for direct emissions from N to soil from 1.25 to 1%
- Nitrous oxide emission factor for indirect emissions from leached N from 2.5 to 0.75%
- Nitrous oxide emission factor for sheep excreta N at grazing from 2 to 1%

(*We could do a simple sensitivity analysis for the impact of these changes. However, it is not worth committing to any revisions until the Defra GHG Platform has reported on UK evidence for emission factors*).

Environmental Condition
ADAS modelling system uses MANNER, NEAP-N and NITCAT models to calculate nitrate leaching and indirect N_2O emissions. As a result, emissions will vary spatially in response to rainfall and soil texture.

ADAS modelling system modifies the emission factor for N_2O from N applied to soil to represent impact of soil compaction and poaching. We assume that all managed grass fields have a small permanent visibly poached area around tracks and feeders that covers 2% of the field area. We also assume that all fields that have reported evidence of poaching damage had an additional seasonal visibly poached area (3%) on and around gates and camping areas, and a more widely spread permanent area (20%) of less visible compaction and sparse vegetation cover. Oenema *et al.* (1997) in a review of N_2O emissions from grassland cite a 2 to 3.6 fold increase of emissions due to compacted grassland soil. Bhandral *et al.* (2007) measured N_2O emissions from compacted grassland soils that were 3.6 to 6.7 times greater than from non-compacted soils receiving urine, ammonium and urea; and up to 18 times greater for soils receiving nitrate. van Groenigen *et al.* (2005) reported that N_2O emissions of urine applied to a sandy soil increased 5 fold when the soil was compacted under moist conditions, which was comparable to a factor of 3.5 reported by Yamulki and Jarvis (2002). Matthews *et al.* (2010) reported N_2O emissions from gateways and poached land around water trough that were 10 times greater than from neighbouring managed pasture. Finally, Smith and Smith (2004) used a constant multiplier of 2 for fields grazed by cattle; and 1.3 for fields grazed by sheep for an improved calculation of N_2O emissions for Scotland. This was a landscape scale multiplier against emissions from mineral fertiliser that is assumed to represent the net effect of poached and non-poached fields.

Based on this evidence, we used a N_2O emission multiplier of 10 for the visibly poached areas of a field (2 to 5%) and a multiplier of 5 for the wider damaged soil area (20%). The net impact of this was that N_2O emissions were increased by a factor of 2.25 on poached fields, and by 1.18 on all non-poached fields. At landscape scale, and assuming that 50% of fields were poached, the net N_2O emission would be increased by a factor of 1.7 in the absence of mitigation. We believe that this multiplier is both representative of the empirical literature and comparable to the landscape scale treading coefficient used by Smith and Smith (2004). The exception here is that we apply the factor to losses from nitrogen in all of fertiliser, manure and excreta rather than just mineral fertiliser as in Smith and Smith (2004). For this work we did not make a distinction between grazing by sheep and cattle as this was implicitly represented by the survey evidence on the increased incidence of poaching on the dairy farm type.

Farm Practice
The ADAS modelling system calculates emissions from managed manures using animal / farm type specific and Welsh survey data on the proportion of manures managed as FYM and slurry. As the emission factors for FYM and slurry are very different this may result in different emission totals compared to calculations using the UK Inventory default values for management practices that are UK averages.

Mitigation
The ADAS modelling system represents the effect of a small number of mitigation methods affecting N_2O and CH_4 emissions. Most of these are indirect, i.e. reductions in nitrogen inputs or methods to reduce nitrate leaching. Methods are represented as a percentage modifier to the default emission factors, also modified by estimates of uptake of the method.

For N_2O, there are additional direct impacts of: minimal cultivation; avoiding application of manure or fertiliser at high risk times; rough ploughing and other soil management techniques (to remove soil compaction effects);

For CH_4, there are additional direct impacts of: covering FYM heaps; and reduced concentrate use on organic farms.

LULUCF emissions reporting system (Janet Moxley and Heath Malcolm)
The LULUCF reporting quantifies emissions and removals associated with changes in land use and some land management practices for inclusion in the UK Greenhouse Gas emissions inventory. Direct emissions of soil- CO_2, CH_4 and N_2O from this sector are included, but it does not include emissions allocated to the Agriculture sector, such as N_2O emissions from fertiliser application. It includes emissions due to changes in above- and below-ground biomass, soil and dead organic matter, and emissions of CO_2, CH_4 and N_2O from wildfires and biomass burning during deforestation. Emissions of methane and nitrous oxide from agricultural activity are captured in the Agricultural sector of the greenhouse gas inventory.

The IPCC LULUCF reporting system uses activity data from surveys such as the Countryside Survey, Agricultural Censuses and the National Inventory of Woodland and Trees to assess areas subject to different land uses, and to some extent is able to incorporate information on areas subject to different land managements. Because the finest scale for many of these data is the individual administration level, it is not sensitive to the local causes of variation such as climate, or soil. A “vector” approach to land use change is being developed for implementation in the 1990 – 2014 inventory. This will use the IACS Land Parcel Identification System data supplemented with remotely sensed data from the CORINE dataset to make the model spatially explicit and allow better integration with other datasets.

LULUCF reporting can use three Tiers of reporting of varying complexity to assess emission from the Land Use, Land Use Change and Forestry sector. Tier 1 is the simplest level of reporting, and Tier 3 the most complex. Tier 1 and 2 reporting are used for most activities. Tier 1 reporting uses national (UK) level activity data from censuses and surveys and default emission factors given in the IPCC Guidance. Tier 2 reporting uses higher resolution activity data (devolved administration or regional level) and UK-specific emissions factors where available. Tier 3 reporting uses modelling to assess emissions and is only currently used for the emissions from LULUCF activity related to Forestry (including deforestation to other land uses). Forest Research’s CARBINE model (Forest Research) was used for the first time in the 2012 Inventory replacing the simpler CEH C-Flow model.

While LULUCF reporting captures land use change and has the potential to capture emissions from land management activity, the UK has currently only elected to report on a limited number of land management interventions on agricultural land, namely liming of grassland and cropland, emissions from wildfires, emissions from drainage of peatland for use as Cropland, removals due to changes in the biomass of agricultural crops due to improved agronomy, and emissions from peat extraction. A Defra funded project, SP1113, has developed a methodology for capturing emissions from changes in soil carbon stocks due to land management activities on Cropland, which will be implemented in the 1990 – 2012 inventory. The project attempted to model emission factors for a range of Cropland management practices, but scarcity of long term UK-relevant field data to calibrate and validate the model meant that confidence in the output was very low. Because of this Tier 1 emission factors will be used for most activities except for tillage reduction where both the literature review and the modelling work suggested no effect under UK conditions when the full soil depth was considered and bulk density effects were accounted for. , and Lack of data on the effect of Grassland management, particularly the effect of management of grassland on upland soils meant that it was not possible to set up a reporting framework for this at present. DECC funded work will look at the effect of land management on emissions and removals due to changes in biomass carbon stocks on Grassland and perennial Cropland is in progress.

Model outputs
LULUCF outputs include:

- CO_2 emissions and removals from change in soil carbon stocks associated with land use change.
- CO_2 emissions and removals from change in biomass carbon stocks associated with land use change.
- Emissions of N_2O from soils as a result of disturbance during land use change.

- Emissions of CO_2, CH_4, and N_2O from biomass burning during deforestation to other land uses and wildfires on all land use types.
- Emissions of CO_2 from carbonate used in liming Cropland and Grassland.
- Emissions from drainage of peat (histosols) for use as Cropland.
- Emissions from peat extraction and use.
- Emissions and removals from change in residue and manure inputs to Cropland.
- Emissions and removals from change between annual and perennial crops.

Recent applications of the model

The LULUCF reporting system is used for annual reporting of emissions and removals by the LULUCF sector in the UK as required to meet international reporting requirements under the UN Framework Convention on Climate Change, the Kyoto Protocol and the EU Monitoring Mechanism. As part of these reporting processes it produces reports for each UK administrations and maps emissions to local authority areas.

Emission Factors

The IPCC Guidance on LULUCF reporting gives default emission factors which can be used where no more specific national or regional factors can be identified. However, UK or regional emission factors are available for some activities (Table 2).

Emission Source	EF Tier	Comments
Change in biomass carbon stocks in biomass, soils and dead organic matter (DOM) Forests and deforested land	3	Carbon stocks in Forest biomass, soils and DOM are obtained from the Forest Research CARBINE model (Forest Research), which includes yield data for all tree species in the UK (Edwards and Christie, 1981) and includes information on the distribution of tree types within the UK. This feeds into assessment of removals by the forestry sector as well as emissions from deforestation to other land uses. When land is deforested, it is assumed that 60% of living biomass is removed for timber, and the remaining biomass and dead organic matter (DOM) is burnt.
Emissions from Forest burnt in controlled burns during deforestation and in wildfires	3	Stocks of living biomass and DOM are obtained from CARBINE. Other emissions factors are default IPCC Tier 1 factors
Soil carbon stocks for non-Forest land	2	Obtained from a database of soil carbon density (Bradley et al, 2005).
Biomass carbon stocks for non-Forest land uses	2	Derived from Milne and Brown (1997),
Emissions from carbonate used in liming	1	IPCC default values based on chemical stoichiometry
Emissions from peatland drainage for cropland	3	Has been modelled using Century (Burton 1995; Bradley 1997). However the work used as this basis for this modelling does not account for bulk density changes, so it is proposed to revert to IPCC default factors from the 2006 Guidelines, pending development of Tier 3 emission factors in the process of work to implement the Wetlands Supplement.
Removals due to crop yield improvements	2	Change in plant biomass predicted to follow trend 1980 – 2000 (Sylvester-Bradley et al, 2002)

N_2O from soil disturbance during conversion to Cropland	1	IPCC default emission factors
Onsite emissions from peat extraction	1	IPCC default emission factors
Emissions from horticultural peat	2	Carbon content taken from Thomson et al (2011).
Effect of cropland management on soil carbon stocks	1	IPCC default stock change factors

Table 2. Sources of emission factors for LULUCF emission sources.

Environmental Condition

The LULUCF reporting system uses a broad brush approach which is not spatially explicit and so is generally not sensitive to environmental condition. The exception is data on Forest carbon stocks generated by the CARBINE model which takes account of variation in climate and soil.

It is planned to implement a spatially explicit approach using land use vectors from the 1990 – 2014 inventory which will allow better consideration of environmental conditions such as soil type, climate or slope.

Farm Practice

The effects of land use change between Cropland and Grassland are captured. The SP1113 project has started to develop a vector approach to mapping land use change between Cropland and Grassland based on IACS data. It is intended to fully implement this in the 1990 – 2014 inventory this will improve estimation of rotational practices. The effects of key Cropland management practices affecting CO2 emissions will be included in the 1990 – 2013 inventory. (Agricultural emissions of non-CO2 greenhouse greens are captured in the Agricultural inventory. Creation of farm woodland and tree planting is only partially captured in the LULUCF inventory, as the definition of woodland is taken from the National Forest Inventory and does not include wooded areas of less than 1 ha or areas with a potential canopy cover of less than 20%. This means that small farm woodlands, shelter belts and hedges may not be included.

Similarly changes of use from Cropland to Grassland which only cover small areas such as riparian buffer strips and uncultivated field margins may not be captured in the Countryside Survey data, which is currently the main source of data used to generate the land use change matrices used in LULUCF reporting although data on afforestation and deforestation is obtained from Forest Statistics and felling licence data which are updated annually. The use of Countryside Survey data to assess land use change also limits the sensitivity of LULUCF reporting to land use change in the short term as Countryside Surveys are only carried out approximately decadally. From the 1990-2014 inventory onwards IACS data will be used as the main source of data on land use in agricultural areas, however it is not clear whether or not this will be better at capturing practices which affect small areas of land on farms.

The LULUCF reporting system only captures a limited number of farm practices at present, namely direct emissions from liming and changes in biomass of agricultural crops due to improved agronomy. From the 1990 – 2013 inventory onwards it will include the effects of change in soil carbon stocks resulting from manure and residue inputs to Cropland and will distinguish between annual and perennial crops. It has not been possible to develop a framework for assessing the effects of Grassland management on soil carbon stocks because of lack of information, particularly with regard to upland grassland. The DECC project is currently assessing the feasibility of incorporating the effect of Cropland management on stocks of living biomass.

Mitigation

LULUCF reporting captures the effect of a limited number of mitigation options. It does capture the effect of land use change e.g. change from Cropland to Grassland or Grassland to Forest. However as discussed above there are some limitations to the sensitivity of this reporting in terms of the minimum change of area included, definitions of Forest and the timescale for detecting change which for change between Cropland and Grassland depends on Countryside Surveys.

LULUCF should capture reductions in emissions due to reduced liming, but this is assessed using disaggregated GB data, so may not be sensitive to initiatives taken specifically in Wales unless these are replicated by other GB administrations.

From the 1990 – 2013 inventory the effect of Cropland manure and crop residue inputs on soil carbon stocks will be included and a distinction made between annual and perennial crops. Tillage reduction was not found to have any effect on soil carbon stocks under UK conditions when the whole soil depth was considered and bulk density effects taken into account. Reporting on the effect of land management on Grassland has proved more problematic because of the difficulty in assessing the effect of intensification on different Grassland types. Work is currently underway to assess the effect of Cropland management on biomass stocks. Only perennial crops act as permanent store of biomass. While only small areas are likely to be involved, policies to increase production of biomass fuels could be reflected in LULUCF reporting if suitable activity and stock change factor data is available.

The Bangor Carbon Footprinting Model (Rachel Taylor)

Model description
The Bangor CF takes real farm data on all inputs, land management practices (and history for Land Use Change) and monthly stock diary data to generate annual C footprints that are PAS 2050 compliant (unless soil and biomass C sequestration effects are included). It adopts Tier 1 emission factors for most N_2O and CH_4 emissions (enteric fermentation based on animal category numbers and bodyweights x average EFs; soil emission factors; manure storage by type *etc*…). But it includes a simplified Tier 2 estimate of soil C accumulation under grassland, and accounts for on-going C sequestration in tree biomass. A monthly stocking diary enables more accurate estimation of annual enteric fermentation (x animal numbers) and manure management (N excretion and CH_4 EFs). It takes a Life Cycle Analysis approach, and boundaries include embedded GHG emissions associated with feed and fertiliser production and transportation to the farm.

Model outputs
The Bangor CF Tool outputs include: gases - enteric methane, manure methane, direct excreta, soil and manure heap N_2O; N_2O associated with nitrate leaching and N deposition (indirect N_2O); CO_2 from energy use; embedded greenhouse gas emissions associated with inputs (feed, fertiliser, agrochemicals, pharmaceuticals, significant consumables); and agricultural productivity. Above and below ground carbon annual increments in soils and biomass are modelled and reported separately from the system GHG emissions framework.

Recent applications of the model
The Bangor CF Tool was initially developed to assess the policy-relevant GHG emissions and carbon-sequestration impacts of a sustainable farming initiative in mid-Wales (Taylor et al. 2010); and for research into GHG emissions from mixed farming systems (Wyn Jones et al. 2011, Taylor et al. 2014). Further development took place under a previous Welsh Government funded project to assess the contribution of previous Welsh agri-environment schemes to the maintenance and improvement of soil and water quality, and to the mitigation of climate change (Taylor et al., 2012; chapter in Anthony et al 2012). It is currently being used in a number of projects to assess GHG impacts at the farm scale, including the annual variability in farm GHG emissions and the development of novel forage proteins for livestock production.

Emission Factors
The Bangor CF Tool generally uses IPCC Guidelines (2006) emission factors for calculating CH_4 and N_2O emissions from agriculture, maintaining compliance with PAS2050 where specific emissions factors are required for farm practices. Default emission factors are used with farm-specific management and productivity data (e.g. fertiliser use and dairy cattle milk yield) and livestock numbers and age classes are recalculated iteratively for each month of the farming year. Adherence to IPCC Guidelines means that model is consistent with UK Inventory methodology. Any additional emission factors are selected from a review of the published literature on UK based field studies, in order to reflect as closely as possible the Welsh climate and natural soil attributes for N_2O - e.g. including the effects of temperature, atmospheric CO_2, pH, organic matter content, saturation and aeration. For example, the IPCC standard EF used for N_2O emissions from managed peat soils is 8 kg (range 2 – 24) N_2O-N ha^{-1}, but we currently apply the ECOSSE model value of 0.25kg (range -0.99 – 3.7) N_2O-N ha^{-1}, calculated for a North Wales study site (ECOSSE 2007).

N budget and N_2O emissions modelling
The Bangor CF Tool calculates the farm year organic N budget from livestock diaries using breed- and farm-specific animal growth rates; and mineral N from fertiliser formulation-use data. Stored manure (including incorporated bedding materials) and direct-deposition organic N (excreta and daily-spread manure) are modelled separately based on farm practice data.

Nitrate leaching, direct N and indirect N_2O emissions are calculated as emissions and losses from stored manures using IPCC standard Tier 1 methodology, with reference to farm storage practices (aerobic/anaerobic, lagoons etc.) specific to each animal type. Soil N_2O emissions are calculated from applied organic N (stored manure corrected for storage losses specific to store method), excreta organic N and applied mineral N (IPCC (2006) EF of 0.01 (0.00 – 0.03) kg N_2O-N kg^{-1} N applied to total N content of all fertiliser formulations applied) per IPCC guidelines. Additional N_2O emissions are calculated per unit area of peat soils reported by the landowner and under management which includes N deposition (fertiliser, manure, grazing); corresponding to “managed peat soils” per IPCC recommendation and using a Wales-specific emission factor (ECOSSE).

Methane emissions modelling

The Bangor CF Tool calculates manure and excreta CH_4 emissions from the detailed livestock diaries using breed- and farm-specific animal growth rates. Monthly livestock numbers per animal type and age class are used with IPCC Tier 1 methodology and published relevant emissions rates for the relevant UK production systems. In order to avoid double-accounting, emissions from animals on the farm that remain the property of another holding (eg. ‘tack’ sheep) are calculated separately: their direct emissions remain within the system boundary of their home farm, whilst soils and excreta emissions (N_2O and CH_4) are incorporated into the farm on which they are grazing.

Farm inputs

The Bangor CF Tool calculates embodied GHG emissions and transport emissions from point-of-sale to the farm gate for all farm inputs that can be identified and quantified. Farm inputs are identified during discussions with farmers, and details of their provenance, purchased amounts, transport method etc. collected in all available detail. PAS2050 allows the exclusion of inputs only where their GHG impact represents less than 5% of the total emissions footprint, as long as the total GHG value of all excluded inputs also remains below this 5% threshold. For each input, the embodied GHG emissions may be (in order of preference) a) extracted from relevant published PAS2050-compliant studies including IPCC databases; b) estimated using published or collected formulations or production data (relevant to fertilisers and animal feeds); c) estimated using data for farm exports calculated using the Bangor Tool during previous studies (relevant to bought-in livestock) or d) estimated using nearest-equivalent generic values from GHG emissions databases.

For inputs with annually-varying embodied GHG values, the published emissions value for the year in which the inputs were purchased is used (relevant to electricity and fuels). For complex inputs such as animal feeds, GHG emissions are calculated using feed formulation and individual ingredient provenance and published footprint data sourced in the same way as for other farm inputs.

Uncertainty

Citing a single precise figure as the output of a carbon footprinting exercise may be misleading as GHG calculations have to deal with issues of variability, uncertainty and subjectivity, each of which can reduce the accuracy and precision of the final result. For example, within the agricultural context, there is tremendous biophysical variability between farms producing the same products, and this can generate large differences in the calculated GHG emissions of the farm business. Welsh Lamb may be produced on an upland farm where there are very few inputs, but there is also low productivity per hectare; or on fertile lowland farms with higher unit productivity but more fertiliser input. Management also varies between farmers; and even neighbouring farms of the same type, e.g. dairy producers, can have different yields and GHG footprints which are partly a function of the personality and skills of the farmer. The weather can also have a large impact on the way a farm is managed. As a result the exact footprint of a farm may vary over time due to interactions between the climatic environment and the associated management decisions of the farmer. Finally, carbon footprints vary with the underlying soil type. As a result the underlying soil type of a farm can have a large impact on the final footprint for that farm. This sort of variation has not typically been reported in carbon footprints to date, but in the Welsh context Edwards-Jones et al. (2009b) suggest that the footprint from farms on organic (peat-derived) soils can be substantially greater than those on mineral soils.

In addition to genuine biophysical variation between farms and years there is also considerable uncertainty inherent in GHG emission factors. This uncertainty is related to the limitations of our understanding of ecosystem-level processes. Emission factors reported in standard databases are derived from studies using a range of system boundaries, data collection techniques, data definition and processing methodologies etc. The choice of emission factor database is a subjective process, while the variation between emission factors for the same process can introduce variability into the process of carbon footprinting. The scientific literature presents a range of emission factors for most processes. However, scientific understanding of these complex processes is limited, partly because their measurement is time-consuming and spatially and temporally variable. The IPCC approach to this problem has been to produce standard emission factors through meta-analysis of all the available experimental data. These may be applied worldwide or be relevant to large geographical regions, but can have limited relevance to local conditions.

In addition to variability and uncertainty, carbon footprints also include an element of subjectivity: the analyst is required to represent a real farm in a simplified form, which requires a series of simplifying assumptions to be made. It is important that analysts recognise the subjective nature of their activities. To date, few studies have tried to report this uncertainty and variability (exceptions include Edwards-Jones et al. 2009, Lloyd & Ries 2008). Similarly, many of the studies reported in the literature have used modelling approaches, rather than using real farm data: which does not allow for an assessment of differences between individual farms (e.g. Williams et al. 2006; Weiske et al. 2006; Hirschfeld et al. 2008).

The Bangor CF Tool retains uncertainty throughout the calculation process by presenting three sets of calculation results. The commonly cited value is calculated using the mid-values for all emissions factors, the value considered by the authors of source studies to be the most likely representation of an accurate value. In addition, a result is calculated using the maximum range values for all emissions factors (worst-case scenario) and a third result using the minimum range values (best-case scenario). These extreme values are likely to represent the absolute maximum range of possible GHG emissions produced by the farm system under analysis.

Mitigation

A completed Bangor CF Tool is, in effect, a virtual model of an individual farm in a specified business year. The model is made very detailed to reflect that farm system and the management practices developed by the individual farmer, but it retains as calculation options all the alternative management practices specified by IPCC and encountered during previous Bangor farm modelling work. In consequence, it is possible to alter any component of the virtual farm and look for GHG impacts of such changes. Potential mitigation methods affecting N_2O and CH_4 emissions would include manure storage (aerobic/anaerobic methods, digesters), fertiliser application rates, livestock types and stocking rates. Other possible mitigation options including dietary changes can be modelled by applying appropriate Tier 1 emissions factors from published literature or other model outputs (as % modifiers to soil emission rates, for example).

A range of other potential options for reducing GHG emissions can be applied to the virtual farm. These include modifying inputs such as energy use (including investment in self-generation and renewables) or livestock feeds. Feedstuff modification can be a simple reduction in feed purchase, or a change to feed formulation (e.g. reduced protein content, change of protein type) or feed provenance (switch from South American to EU-grown soya).

Arable crops and Land-use Change data

Nitrous oxide emissions from arable land are calculated per IPCC guidelines for soil area, crop type and yield data collected from the farmer. Crop residues are modelled as removed (grazed, harvested) or incorporated (e.g. stubble ploughed-in) depending on stated management practices, and N_2O emissions associated with the N content of incorporated residues are calculated in accordance with IPCC guidelines.

For land areas under management that has changed in the last 20 years, default land-use change values from Jones and Emmett (2009) and other relevant published literature are applied on an area basis. Relevant changes include C loss consonant with ploughing permanent grassland (to re-sow grassland or add to arable rotations); or C gains associated with woodland and hedgerow planting. C impacts of land-use change occur over a period of time (e.g. ploughing impacts occur in the first year, tillage changes over 10 years, etc) and the C impacts are modelled for one year's net impact after the stated number of elapsed years. These soil GHG impacts of land-use change are included in the PAS2050-compliant emissions calculations, and soil areas subject to such changes are excluded from the C sequestration (soils) calculations.

Few data are available on the C implications of land-use change (DEFRA REVIEW SP1113). The values applied in the Bangor CF Tool are those associated with significant management changes, taken from Jones and Emmett (2009). On cropland the most commonly applied changes are conversion to grassland (+3.2t CO_2e ha^{-1}, 100% in year 1) and hedgerow planting (+0.05t CO_2e ha^{-1}, 100% in year 10). Improved grassland changes commonly include conversion to permanent grassland (+1.01t CO_2e ha^{-1}, 100% in year 1), hedgerow planting (as for cropland) or woodland planting (+0.88t CO_2e ha^{-1}, 100% in year 30 to 50); for reduced grazing impacts on semi-natural grasslands the GHG impact applied is (+2.84t CO_2e ha^{-1}, 100% in year 1). For some of these changes a range of values are presented in (DEFRA REVIEW SP1113); for example the conversion of cropland to grassland GHG impact is +0.87t C $ha^{-1}yr^{-1}$ (Germany) and +0.5t C ha^{-1} yr^{-1} (Sweden) which represent +3.19 and +1.84 t CO_2e ha^{-1} yr^{-1}, both considerably higher than the UK values.

Land-use change GHG calculations are applied for changes in soil C (as CO_2e). Where a land-use change includes significant biomass change (woodland conversion including hedgerow planting), biomass values are calculated independently using forest growth models (see section on C sequestration). A cautious approach is taken over land-use change from detailed management (e.g. changes in fertiliser type or crop type) as these changes are often difficult to clarify with farmers or represent gradual alterations in practices rather than the activity of a particular year. The subset of land-use changes most commonly applied are summarised in Table 3 and represent midpoint emissions values taken from Jones and Emmett (2009).

Land use type	**Land use change**	**Greenhouse gas emissions (EF)**		**Mitigation potential after elapsed time**			
	(cf. Jones and Emmett 2009)	(t CO_2 eq/ha/y^{-1})		(% of maximal annual emission rate)			
		midpoint	range	1 year	10 years	30 years	50 years
Croplands	Enhanced fertiliser management (N/lime)	0.72	0.02-1.42	100	30	5	0
	Set aside and field margins	3.21	0.00-6.41	100	95	10	0
	Conversion to grassland	3.2	0.00-6.40	100	95	10	0
	Agroforestry / hedgerow	0.05	0 - 0.1	10	100	10	0
	Conversion to forestry (managed)	0.85	0.3-1.4	10	50	100	10
	Conversion to forestry (unmanaged)	0.85	0.3-1.4	5	15	50	100
Improved Grasslands	Stop re-seeding (i.e. reduced tillage)	1.01	0.73-1.28	100	90	15	5
	Agroforestry / hedgerow	0.05	0.00-0.10	10	100	10	0
	Conversion to forest (managed)	0.88	0.37-1.38	10	50	100	10
	Conversion to forest (unmanaged)	0.88	0.37-1.38	5	15	50	100
Semi-natural Grasslands	Agroforestry / hedgerow	0.05	0.00-0.10	10	100	10	0
	Conversion to forest (managed)	0.88	0.37-1.38	10	50	100	10
	Conversion to forest (unmanaged)	0.88	0.37-1.38	5	15	50	100

Table 3. Effects of land use change on soil C stocks, expressed as CO_2 eq ha^{-1} y^{-1}.

A comprehensive review of soil C under land-use change (Poeplau et al. 2011) compiled data from 95 studies covering 322 temperate zone studies in order to model soil C change in topsoil (30cm depth). Values from this study converted to annual C change are represented in CO_2e ha^{-1} and compared with the model values from Jones and Emmett (2009) (Table 4).

The values used in the Bangor model for cropland converted to grassland, and grassland converted to forest are very similar to those in the meta-review. This review calculated higher emissions values for croplands converted to forest, although the range of values included in the review encompasses the value from Jones and Emmett (2009). The authors noted that C accumulation in forest soil was a linear relationship (IPCC assumes that soil under woodland reaches C equilibrium after 60 years) and was strongly influenced by mean annual temperature; this may be the reason for the more conservative values Jones and Emmett applied to Welsh soils.

Land-use type	**Land-use change**	**GHG emissions ($t\ CO_2\ eq/ha/y^{-1}$)**				Equilibrium (years)	**Mitigation potential development after conversion**							
							% maximum GHG emissions or *% of initial C stock							
		over 20y		over 100y			1 year	10 years	20 years		30 years	50 years	100 years	
Croplands	Cropland to grassland	3.37	±6.19	2.18	±3.7	>120			*39.8	± 11			*128.4	± 23.2
	Jones& Emmett 2009	***3.20***	***± 0.70***			***30***	***100***	***95***			***10***	***0***		
	Cropland to forest (only mineral soil)	1.63	±3.81	1.70	±3.96	>120			*16	± 7.4			*83.4	± 38.8
	Jones& Emmett 2009	***0.85***	***± 0.55***			***30-50***	***5-10***	***15-50***			***~100***	***~100***		
Forest	Forest to cropland	-8.46	±-3.99	-1.74	±-0.88	23			*-31.4	± 20.4			*-32.2	± 19.9
	Jones& Emmett 2009	***-0.85***	***± 0.55***			***10***	***5-10***	***15-50***			***~100***	***~100***		
Grasslands	Grassland to cropland	-7.61	±-10.45	-1.52	±-2.09	17			*-36.1	± 4.6			*-36.1	± 4.6
	Jones& Emmett 2009	***-3.20***	***± 0.70***			***30***	***100***	***95***			***10***	***0***		
	Grassland to forest (only mineral soil)	-0.61	±-0.11	-0.18	±0.69	>150			*-4.3	± 3.7			*-6.5	± 22.6
	Jones& Emmett 2009	***-0.88***	***± 0.50***			***30-50***	***5-10***	***15-50***			***~100***	***~100***		

Table 4. Effects of land use change on soil carbon, expressed as CO_2 eq $ha^{-1}\ y^{-1}$: a comparison of studies.

The greatest disagreement in values is in the conversion of forest to cropland, although the value from Jones and Emmett (2009) is within the range of values for annual change over 100 years from Poeplau et al. (2011). This value represents only 15 studies, and the authors note the impact of limited data (high scatter and therefore high uncertainty in model fit); of soil type (higher soil C loss from clay soils) and mean annual temperature (higher C loss in warmer climates). Clay soil is relatively uncommon on Welsh farms and the climate is cool, supporting the decision to use values at the low end of the reviewed range.

Modelling carbon sequestration in soils and biomass

Carbon sequestration in soils and biomass is modelled independently of the PAS2050-compliant GHG emissions components of the Bangor CF Tool, and of the land-use change calculations but uses the same Tier 1 approach and retains the same flexibility for scenario modelling. Calculations fall into the following categories:

a) ≥75% closed-canopy trees (woodland and forestry) over 20yo – modelled as woodland by area using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species or species mix) assuming stable soil carbon content. Timber extraction modelled as carbon losses sensitive to brash handling (burning, composting) and including litter decomposition.
b) ≥75% closed-canopy trees (woodland and forestry) under 20yo – modelled as woodland by area using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species or species mix) assuming increasing soil carbon content.
c) Dispersed or isolated trees including emergent from hedgerows – counted by landowner – are modelled as free-grown standards using site-specific Forestry Commission tree growth models (soil, aspect, altitude, rainfall, species mix).
d) Hedgerows are measured from aerial photographs in consultation with landowner. Hedges flailed in the sample year are assumed to maintain biomass equilibrium. Hedges not flailed in the sample year are modelled using growth increments for the equivalent area (length x width) of established alley-cropped short-rotation coppice. Boundary hedges (with neighbouring farms) are assumed to be shared-ownership and 50% of their area excluded to avoid double-accounting un up-scaling results to national estimates.
e) Soil C sequestration is considered to be in equilibrium under arable and rotational (improved) grassland. For permanent grassland on mineral soils, a low-average default net ecosystem change value for UK grasslands of 0.24 t $ha^{-1}y^{-1}$ (range 0.04 – 0.44 t $ha^{-1}y^{-1}$, Janssens et al. (2005)) is used, pending further review of studies relevant to Welsh agricultural land. Buckingham et al. (2013) acknowledge the scarcity of relevant data for Welsh grassland but cites a similar rate of increase in SOC of 1 to 4 t ha^{-1} over 10 years as a consequence of manure application. For permanent grassland on organic soils default C sequestration rates for unmanaged peatlands are taken from Watson et al. (2000) (IPCC special report).

Productivity

The Bangor CF Tool also incorporates details of production (sales and exports by weight) for all farm produce in the sample year. These data are used to allocate GHG emissions to products for the purposes of product and supply-chain GHG footprinting beyond the farm gate. Allocation to products is compliant with PAS2050 and separates farm enterprises (direct and indirect emissions from cattle enterprise allocated to cattle products) as completely as possible. Notable exceptions include agrochemicals applied to pastures grazed by livestock from different enterprises (sheep and cattle), and energy inputs (electricity and diesel) which are allocated economically by enterprise sales revenues. 75-90% of total emissions can generally be allocated directly to the correct enterprises. A collateral benefit of these data is to investigate the potential impacts of mitigation or agri-environment scheme practices on production, with obvious benefits for predicting impacts of such schemes on national food security.

ECOSSE (Mohamed Abdalla and Pete Smith)

Model Description

The ECOSSE (Estimating Carbon in Organic Soils - Sequestration and Emissions) model was developed to simulate soil organic carbon (SOC) in highly organic soils from concepts originally derived for mineral soils in the RothC and SUNDIAL models. ECOSSE contains additional descriptions of a number of biogeochemical processes in mineral soils, including simulation of anaerobic processes in organic soils (Smith *et al*. 2007, 2010c). It uses a pool type approach, and all of the major processes of C and N turnover in the soil are included and described using simple equations driven by readily available input variables. It can be used to carry out site-specific simulations with detailed input data, or national-scale simulations using the limited data typically available at larger scales. Data describing SOC, soil water, plant inputs, nutrient applications and timing of management operations are used to run the model. In the case of missing information, it can still provide accurate simulations of GHGs (N_2O associated with nitrification and denitrification, CO_2 corresponds to heterotrophic respiration and CH_4 through a balance between methanogenesis and methanotrophy) and changes in SOC stock. It can be used for both organic and mineral soils, providing accurate values of net change to soil C and N in response to changes in land use and climate. This model calculates outputs for each soil layer for each time step. Thus, it may be used to inform GHG inventories at the field and national scale, assess mitigation options and provide information for policy decisions.

Model outputs

ECOSSE model outputs include: soil methane, soil CO_2 (heterotrophic respiration), soil N_2O (direct), soil carbon stocks and above ground carbon stocks.

Model applications

The ECOSSE model has been applied at both national and European levels. It was used to simulate soil nitrogen, nitrous oxide emissions and mitigation in European croplands (Bell *et al*., 2012). The model was also applied to simulate Rh and attribution to variability in natural and anthropogenic drivers in European peatland ecosystems (Abdalla *et al*., 2014) and soil carbon under short rotation forestry energy crops in Britain (Dondini et al., 2014).

Emission Factors

ECOSSE model can be used to calculate emission factor for N_2O by, for example, subtracting simulated cumulative (seasonal/annual) flux data for unfertilized fields from that of the fertilized fields, and dividing by the amount of N fertilizer applied. EFs can be further evaluated by integrating the predicted daily fluxes (seasonal/annual), and the corresponding measured values. Khalil et al. (2013) successfully predicted measured EF, using ECOSSE, for an 8-years N_2O study on Irish croplands. Emission factors on national and regional levels can also be calculated by using the limited version of the model.

Farm Practice

ECOSSE can be used to investigate how farm management could affect GHG emissions and soil C. Thus, management that increase anthropogenic GHG emissions could be avoided or reduced e.g. drainage could significantly increase CO_2 emissions from European peatlands (Abdalla et al., 2014) and therefore, alternative strategies at a regional level are required. The model can also be used to assess the impacts of potential future land management interventions, and help guide best practice land-management decisions.

Mitigation

The correct estimation for the effects of future climate change and land-use on GHG emissions and C sequestration are essential for advising land use policy on mitigation options. The ECOSSE model can be used to predict these future changes in soil C and N for both mineral and organic soils by comparing GHG emissions and soil C under baseline and future climate and land-use scenarios. The model can provide accurate values of net change to soil C and N in response to changes in land use and climate and can be used to determine uncertainty in national simulations and advise reporting to UKGHG inventories (Smith et al., 2007). ECOSSE is one of the few models suitable for examining the impacts of land-use and climate change on organic soils. Anaerobic decomposition process which result in emissions of CH_4 is included in ECOSSE. In wetlands, methane is produced by methanogenic bacteria in soil when decomposition occurs under anaerobic conditions and is significantly contribute to global warming. The rate of methane emissions are increase with increasing temperature therefore, could have positive feedback due to climate change. ECOSSE estimate CH_4 emissions using a simple but process-based approach. Methane emissions are calculated as the difference between CH_4 production and oxidation, the oxidation process adding to emissions of CO_2. Thus, ECOSSE can help in understanding the processes that control CH_4 emissions, how they react to both environmental and land use changes and predict mitigation options.

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